PAPER

A CONTINUOUS STUDY ON QUALITATIVE ASSESSMENT OF REHYDRATED 'ANNURCA' APPLE: INFLUENCE OF PROCESS CONDITIONS AND DRYING PRE-TREATMENT

B. ÖNAL[A], G. ADILETTA*[A], M. SODO[B], M. DI MATTEO[A] and P. RUSSO[C]

[a]Department of Industrial Engineering, University of Salerno, Via Giovanni Paolo II132, 84084 Fisciano, Salerno, Italy

[b]Department of Public Health, University of Naples Federico II, Via Sergio Pansini 5, 80131 Naples, Italy

[c]Department Chemical Engineering Materials Environment, Sapienza University of Rome, Via Eudossiana 18, 00184 Rome, Italy

*Corresponding author: Tel.: +39 089964334

email: gadiletta@unisa.it

ABSTRACT

In a previous paper the effect of chemical pre-treatment on quality attributes of 'Annurca' apple slabs dried at different temperatures was investigated. Herein, we evaluated the effect of the same pre-treatment on the quality attributes of the same dried 'Annurca' apple samples rehydrated at two temperatures. Specifically, slabs were initially pre-treated in a dipping solution containing trehalose, sodium chloride, sucrose. Then, they were dried by using a convective dryer at 50°, 55°, 60°, and 65°C, and rehydrated at 30° and 70°C by immersion in water. The combination of pre-treatment, drying at 65°C and rehydration temperature of 30°C enabled to obtain the best preservation of rehydration indices (i.e, water absorption capacity), structure and colour properties. On the contrary, the highest antioxidant activity (EC_{50}) in treated samples was found at the lowest drying temperatures (50° and 55°C) among those investigated and rehydration temperature of 30°C. The PCA provided different behaviours among untreated and treated dried apples when rehydrated at 30° and 70°C, demonstrating that this pre-treatment combined with drying/rehydration temperatures influenced the quality attributes of rehydrated samples.

Keywords: 'Annurca' apple, pre-treatment, rehydration, drying, PCA

1. INTRODUCTION

The 'Annurca' apple (*Malus* x *domestica* Borkh. cv Annurca Rossa del Sud) is a temperate and traditional fruit, cultivated in Southern Italy, in particular in the Campania Region. 'Annurca' appleis rich in bioactive components such as polyphenols, flavonoids and anthocyanins which can contribute to fruit quality in terms of nutritional values, flavour and colour (D'ABROSCA *et al.*, 2017).

Drying is a common method used for apple's preservation and for their consumption over long periods of time on the global markets. Drying contributes to extend the shelf life (more than one year) (NOWACKA*et al.*, 2014) and improves food stability by reducing content-microbial growth, water activity, and minimizing chemical deterioration. Furthermore, drying process creates new processed products, such as rehydrated apples, and reducing the cost of transportation and storage (PROIETTI *et al.*, 2018; ROJAS and AUGUSTO, 2018; WANG *et al.*, 2018; BAEGHBALI *et al.*, 2019; RUSSO *et al.*, 2019;).

However, drying can cause some undesirable changes in fruits including browning and oxidation reactions, case hardening and degradation of nutritional compounds. These changes affect the overall quality of dried fruits, as well as the consumer acceptability (WANG *et al.*, 2018; ÖNAL *et al.*, 2019). Moreover, the structure of tissue is partially destroyed, which may affect water permeability, and as a result the rehydration ability and the product texture (KROKIDA *et al.*, 2000; COX *et al.*, 2012).

Most of the dried foods and particularly apples, are usually rehydrated before their consumption, i.e, in bakery products, instant products (soup), milk products (yogurt, ice-cream), fruit tea – infusion and liqueurs. Rehydration is a complex process, which aims for reconstituting the fresh food's properties by contacting dried product with water or other liquids, i.e, fruit juice, sucrose or glucose solution. The rehydration process consists of three steps at the same time: dried food absorbs water, swelling occurs in the rehydrated product, and soluble components are lost or are diffused through the solution (LEWICKI, 1998; MOREIRA *et al.*, 2008; COX *et al.*, 2012). Rehydration characteristics of dried fruits are considered as quality parameters. Such characteristics are influenced by the samples' composition (i.e, protein content, volume and density of dried products), the drying conditions (i.e, temperature and type of process), and the pre-treatment. Moreover, rehydration temperature is the factor that plays major role on rehydration rate, water uptake and volume changes. On the other hand, during rehydration, immersion of the dried food products in water could cause loss of nutrients (i.e, phenolic content, antioxidant activity) and colour pigments (AMIN *et al.*, 2006; MOREIRA *et al.*, 2008; TUNDE-AKINTUNDE, 2008). In this context, the determination of the best rehydration conditions can be appropriate for deeper understanding of rehydration process. Besides, the improvement of quality attributes such as rehydration indices, volume changes, colour, antioxidant activity seems to be crucial to produce high quality rehydrated new products.

The combination of drying temperatures and pre-treatments has been widely implemented in literature leading to improvements in the drying/rehydration process and the quality of final products (i.e, structure, colour, bioactive compounds, sensorial evaluation) and energy savings (LEWICKI, 1998; VEGA-GÁLVEZ *et al.*, 2008; ADILETTA *et al.*, 2015; ADILETTA *et al.*, 2016a; DA COSTA RIBEIRO *et al.*, 2016; ADILETTA *et al.*, 2018; DERMESONLOUOGLU *et al.*, 2018; ÖNAL *et al.*, 2019). In literature there are many studies focused on the application of different dipping pre-treatment solutions to improve fruits and vegetables' rehydration process: ethyl oleate alkaline solution for tomatoes

(DOYMAZ, 2007); citric acid solution and blanching for apple slices (DOYMAZ, 2010); ethyl oleate and sodium carbonate for cape gooseberries (JUNQUEIRA *et al.*, 2017).
Nevertheless, to our knowledge, no work has fully investigated the effect of a pre-treatment on the quality attributes of the rehydrated food product. In this sense, an-in-depth understanding of rehydration process and how it is affected by pre-treatment conditions is essential for the improvement of process design and rehydrated product quality, as well as, for development of new products.
In this work carbohydrate/salt solution is investigated as alternative process protective agents of food products during the drying/rehydration processes. The novel aspect of this work is to clarify the effect of carbohydrate/salt solution on the rehydration phase of dried apples. Trehalose is a naturally occurring and known as one the non-reducing sugars. Trehalose substitutes water molecules in membrane and thereby preventing the phase transition. Trehalose has unique properties on the preservation of the biostructures during the drying process. Moreover, trehalose plays an important role in the minimization of quality deteriorations such as loss of nutrients, protect the colour and flavour caused by Maillard browning reactions (PATİST and ZOERB, 2005; ADİLETTA *et al.*, 2016a; AKTAŞ *et al.*, 2017). The mixture of trehalose with other compounds or trehalose alone becomes important because of its numerous advantages in food drying application (i.e, shorter drying time, enhancement of drying rate, protection of flavour and colour, improvement of reconstitution ofdried foods properties, inhibition of protein denaturation and higher nutritional content) (PATIST and ZOERB, 2005; ATARÉS*et al.*, 2008; OHTAKE and WANG, 2011; XIN *et al.*, 2013; BETORET*et al.*, 2015; ÖNAl*et al.*; 2019).
Most of works are concentrated on the use of trehalose for osmo-dehydrated or freeze-dried food materials (DERMESONLOUOGLOU *et al.*, 2007; XİN *et al.*, 2013). However, detailed information on the effects of trehalose of the rehydrated dried fruits is still lacking, particularly for apple. Therefore, in this paper, trehalose was used as a stabilizer in the preparation of a chemical pre-treatment solution. The addition of sodium chloride salt to this solution aims for improving the texture preservation and the rehydration ability (Lewicki, 1998; DERMESONLOUOGLOU *et al.*, 2007).
Finally, regarding to rehydration process, several papers deal with the modelling of rehydration process of foodstuffs dried with different methods: hot air drying GARCÍAPASQUAL *et al.*, 2006, ZURA-BRAVO *et al.*, 2013); freeze-drying (LOPEZ-QUİROGA *et al.*, 2019; WALLACH *et al.*, 2011); swell drying and vacuum multi flash drying BENSEDDİK *et al.*, 2019). However, limited information is currently available on the effect of rehydration process temperature on the quality attributes of dehydrated products, such as dried edible Irish Brown seaweed (COX *et* al., 2012) and dried apple slices (ZURA-BRAVO *et al.*, 2013).
Therefore, the present work aims to study the quality of rehydrated 'Annurca' apples, both untreated and treated, at two rehydration temperatures (30° and 70°C) (DOYMAZ, 2010). These temperatures resemble the rehydration at approximately room temperature (e.g. milk) and in hot water (e.g. soup, tea, infusion).
In this framework, a combined pre-treatment of trehalose, sodium chloride and sucrose solution was here utilised and its effect, and that of drying and rehydration temperatures, was investigated on the rehydration indices, colour, volume changes and antioxidant activity of the rehydrated apples.
From an industrial perspective, the development of dried foods is a key to provide for commercialization of innovative rehydrated products and to increase consumers' demand of healthier, convenience and ready-to-eat-foods.

2. MATERIALS AND METHODS

2.1. Raw material preparation

'Annurca' apples were obtained from supermarket in Campania Region, Italy, after reddening–ripening treatment (LO SCALZO *et al*., 2001).
Uniform size, without mechanical damage and freshness were used to select the best samples. Several apple fruits were washed with tap water, peeled by using knife and cylinders (30±0.22 mm for diameter and 5±0.01 mm for thickness) were prepared.
Two different type of samples were analysed in this research: apple slabs without any pre-treatment (UTR) and apple slabs treated (TR) by dipping in carbohydrate/salt solution (0.8% trehalose, 0.1% NaCl and 1.0% sucrose); dipping temperature of 25°C and dipping time of 15 min (ÖNAL *et al*., 2019).

2.2. Drying experiments

The treated (TR) and untreated (UTR) slabs were dried in a convectional drier (Zanussi FCV/E6L3) at four different drying temperatures (50°, 55°, 60°, and 65°C), with a constant air velocity of 2.3 m/s. Drying experiments were stop when the moisture content of slabs was about 0.04 kg water/kg db. In order to evaluate the drying kinetics, for each type of samples, three slabs were continuously weighted using a sensor (Phidgets INC., Canada). This weight sensor is a load cell composed of a transducer, which is able to convert mechanical force into electrical signals. The samples' weight loss was recorded online every 5 min.

2.3. Rehydration experiments

Rehydration experiments of apple slices, previously dried, were performed at the specified rehydration temperatures in distilled water by using water bath to evaluate rehydration capacities (DOYMAZ, 2010; BARRERA *et al*., 2016). The rehydration temperatures were selected as 30°C and 70°C on the basis of the literature (DOYMAZ, 2010) for the experimental design of rehydration process. The water to apple ratio was about 100:1 (weight basis). At specific time, samples were taken out from liquid, blotted with tissue paper and measured by using an electronic balance. Slabs were weighted every 15 min in the initial phase of rehydration process (up to 120 min) and then every 30 min.
The rehydration test was performed in triplicate for each apple sample. The rehydration capacity was calculated as percentage water gain (ADILETTA *et al*., 2016a), as follows:

$$\text{Weight gain (\%)} = \frac{\text{(weight of rehydrated samples-weight of dried samples)}}{\text{(weight of dried samples)}} \times 100 \qquad (1)$$

In order to have more information about the amount of absorbed water, the amount of removed solutes, and the degree of cellular and structural disruption during rehydration, four quality indices were investigated (LEWICKI, 1998; BARRERA *et al*., 2016), as follows: (1) water absorption capacity, WAC; (2) dry matter holding capacity, DHC, (3) rehydration ability, RA; and (4) water holding capacity, WHC. The WAC index explains the ability of food material to absorb water that replaces the water removed during drying. The DHC index is a measure of food material ability to hold soluble solids after rehydration; it gives information on tissue destruction and on tissue permeability to solutes. The RA index

describes the rehydration ability of dried product, and it indicates the total tissue destruction caused by both drying and rehydration conditions (MALDONADO *et al.*, 2010). The WHC index measures the ability of product to maintain its own and added water during the rehydration process. Also, WHC has an important role in the food structure modifications (ZAYAS, 1997).
Three indices were calculated by using Eq. (2) to Eq. (4), which proposed to describe the food's behaviour after rehydration process (Barrera et al., 2016). These indices are water absorption capacity (WAC), dry matter holding capacity (DHC), rehydration ability (RA), defined as follows:

$$WAC = \frac{M_R . x_R^W - M_D . x_D^W}{M_0 - M_D} \quad (2)$$

$$DHC = \frac{M_R . (1 - x_R^W)}{M_D . (1 - x_D^W)} \quad (3)$$

$$RA = WAC \cdot DHC \quad (4)$$

where: M is the total mass in g, and x^i is the mass fraction of i component in g/g, the subscripts 0, D and R state the fresh sample, the completely dried and rehydrated samples, respectively, while superscript w states water.
It was also calculated the water holding capacity (WHC) of the rehydrated structure from the soluble solids content of its liquid phase (z) and the amount of liquid (MCF) removed by centrifugation at 4000 rpm for 10 min (Eq. 5).

$$WHC = \frac{M_R . x_R^W - M_{cr} (1 - . z_R^{SS})}{M_R . x_R^W} \quad (5)$$

2.4. Surface colour measurement

The colour parameters of both untreated and treated fresh and rehydrated apple slabs were measured using a colourimeter (Chroma Meter II Reflectance CR-300 triple flash mode aperture 10 mm Minolta, Japan), calibrated previously with a white standard ceramic plate. To analyze the colour change of fresh and rehydrated samples, CIE lab colour coordinates (L*, a* and b*) were recorded and the average values were calculated for each sample. The lightness value (L*) indicates the lightness/darkness of the sample, a* index represents green when negative and red when positive, and b* index represents blue when negative and yellow when positive.
White index (WI), the whiteness degree of samples, was determined as follows (ADILETTA *et al.*, 2016b):

$$WI = 100 - \sqrt{(100 - L*^2) + (a*^2) + (b*^2)} \quad (6)$$

2.5. DPPH radical scavenging activity

Extracts from fresh and rehydrated apple samples were obtained according to D'ABROSCA *et al.* (2017) with some modifications. Methanol solution (10 mL, 80% v/v) (CHROMASOLV®, for HPLC, ≥99.9, Sigma-Aldrich, USA) was added to fresh (5 g ± 0.01) and rehydrated samples (3 g ± 0.01), after reducing to small pieces. The mixture was homogenized throughout an ultraturrax at 10 rpm and then stirred by vortex for 10 min. Supernatant was filtered by using a Whatman No:2 filter paper. All extractions were performed in triplicate.
The total antioxidant activity of allapple slabs was determined by the DPPH radical scavenging method (BRAND-WILLIAMS *et al*., 1995). Different extracts volumes were mixed with 3.5 mL of 6×10-5 M of DPPH methanol solution in cuvettes. The obtained solution was shaken properly and left for 30 min at room temperature in the dark. The absorbance of solution was measured at 517 nm by using UV-Vis spectrophotometer at 517 nm (Lambda Bio 40; PerkinElmer, Waltham, MA, USA). Methanol was used as the blank, while the control sample was without adding any extract. Percentage of inhibition of DPPH radical was calculated as follows:

$$\% \text{ Antioxidant Activity: } (Abs_{control} - Abs_{sample} / Abs_{control}) \times 100 \qquad (7)$$

Where $Abs_{control}$ is the absorbance of control and Abs_{sample} that of the sample.
The results were showed in terms of the EC_{50} value, which was identified as the sample concentration (mg/mL) required to inhibit 50% of the DPPH radical scavenging activity. EC_{50} was determined from a graph of antioxidant capacity (%) versus extract concentration (mg/mL).

2.6. Diameter and thickness evolution

To determine the reconstitution of volume of dried apples, diameter and thickness were measured every 30 min during the rehydration experiments at 30° and 70°C. The average thickness and diameter of UTR and TR samples were calculated as the average of the measured values of 5 slabs for each sample through image analysis (NH Image/ Image J Software 1.8.0). Both dimensions were measured at different positions of the slices and their average value was considered. In particular, the measurement positions on rehydrated apple slabs were as follows: four positions for diameter (along two perpendicular axes and two diagonal axes) and eight positions for thickness (PONKHAM *et al.*, 2012).

2.7. Statistical analysis

All results were repeated three times and they were reported as the mean±standard deviation (S.D). One way analysis (ANOVA) and Tukey test were applied for comparing mean values by using SPSS 24 Software statistics program (SPSS Inc., Chicago, USA). Any statistical difference was considered significant with $p<0.05$ and it was indicated with different letters. Principal component analysis (PCA) was used to identify the principal components contributing to most of the variations within the dataset, evaluating the impact of dipping pre-treatment and drying/rehydration temperatures on the quality

characteristics of rehydrated apples (UTR and TR). All analyses were performed with SPSS software package, version 24 (SPSS Inc., Chicago, USA).

3. RESULTS AND DISCUSSION

In our previous paper (ÖNAL *et al.*, 2019), the impact of a novel and natural dipping pre-treatment containing trehalose, sucrose and sodium chloride, and air drying temperatures (50°, 55°, 60° and 65°C) was evaluated on drying characteristics and quality properties of dried apples. The results demonstrated that, the dipping pre-treatment containing trehalose allowed to decrease drying times, to better retain physico-chemical, nutritional and sensorial attributes (i.e, colour, shrinkage, microstructure, total phenolics compound and antioxidant activity) and obtain high quality of dried apple snacks.
This study is a continuation of our work already published (ÖNAL *et al.*, 2019), and it will provide information on rehydration characteristics of hot-air dried 'Annurca' apple, as well as, rehydrated apples' quality attributes.

3.1. Rehydration kinetics and rehydration indices

The rehydration is an important process, which is used for understanding the quality of dried food products. The physico-chemical changes and structural modifications that occurred during drying, generate cell collapse and volume reductions, reduce the absorption of water, thereby avoiding the complete rehydration of dried products (LEWICKI, 1998; KROKIDA *et al.*, 2003; MOREIRA *et al.*, 2008; ARAL and MEŞE, 2016). This rehydration process is hence affected by several factors, for instance, physico-chemical properties of food, pre-treatment, drying process and conditions.
Results reported in the following refer to apple samples (UTR and TR) dried at four different temperatures (50°, 55°, 60°, and 65°C), and rehydrated at 30° and 70°C.
In order to evaluate the damage of drying and the impact of rehydration temperature on the rehydration behaviour, the weight gain (%) during rehydration was shown in Fig. 1A-B and Fig. 2A-B for both UTR and TR dried apples at temperatures of 30° and 70°C, respectively.

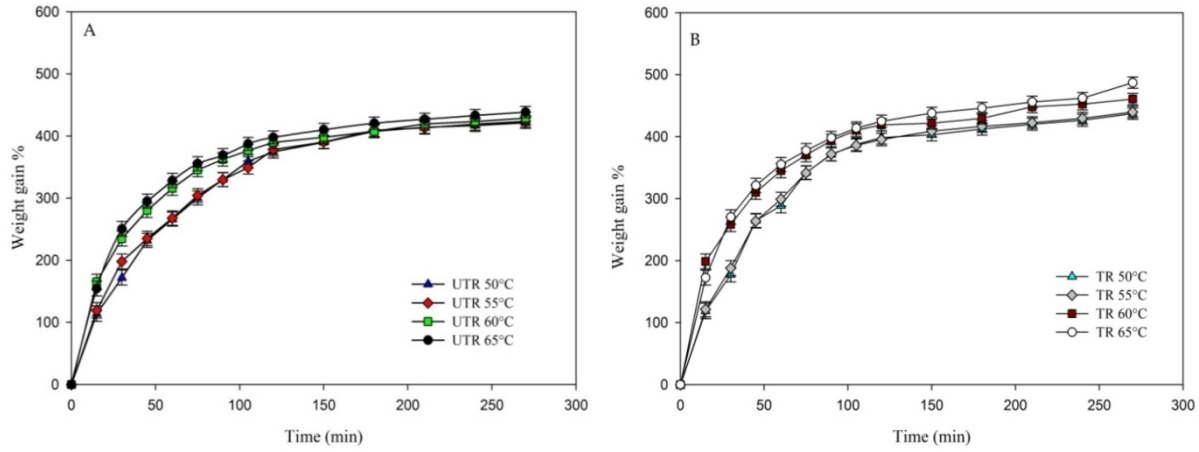

Figure 1. Rehydration kinetics of untreated (A) and treated (B) dried samples (50°, 55°, 60° and 65°C) at rehydration temperature of 30°C.

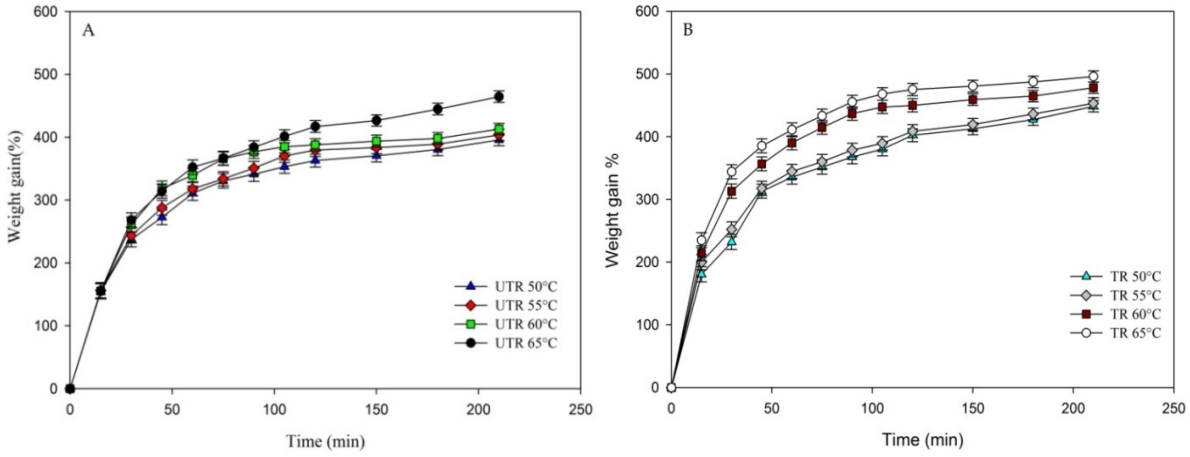

Figure 2. Rehydration kinetics of untreated (A) and treated (B) dried samples (50°, 55°, 60° and 65°C) at rehydration temperature of 70°C.

It was noticed that at any rehydration temperature all the samples showed the same trend. All rehydration curves showed a clear logarithmic trend, and as expected, the rehydration time decreased with increasing temperature from 30° to 70°C. The total rehydration time, that is the time at which a constant water amount was reached, was found as 270 and 210 min for both treated and untreated dried samples, and for rehydration temperatures of 30° and 70°C, respectively.

At the end of the experiments at 30° and 70°C, untreated and treated samples reached almost the same water gain of 420% and 460%, respectively. When rehydration time proceeded, it was observed a reduction in the driving force for water transfer and the system slowly reached equilibrium.

The initial rapid water uptake lasted different times: for both samples at 70°C it was about 30 min with respect to 30°C where it was about 100 min. The fast initial water uptake of curves was detected at rehydration times of 30 and 100 min and that the moisture content on the apples' surface attains the saturation value, almost instantaneously. Hot air dried apple samples exhibited an initial high rate of water uptake followed by a slower rehydration stage that lead to equilibrium moisture values in the rehydration curves– approximately after those times.

The fast initial water uptake is due to the filling of cavities and capillaries near the surface (ÖNAL *et al.*, 2019). Then, the diffusion of water in the pores inside the sample is dominant.

Regarding to the drying conditions, in a previous work (ÖNAL *et al.*, 2019), which analyzed the effect of drying temperatures on drying kinetics and quality properties of dried apples, the optimal drying temperature was found 65°C for preserving the principal quality attributes (i.e, colour, shrinkage, sensorial evaluation and rehydration capacity).

The TR slices showed higher rehydration capacity compared with the UTR ones at both rehydration temperatures. Less rehydration capacity of untreated apples was correlated to the collapse of tissue by higher exposure time during drying. The structure of untreated ones was significantly modified by drying. In other words, the carbohydrate/salt solution containing trehalose here proposed is able to protect apple structure during drying. This is in agreement with the findings reported by ATARÉS *et al.* (2008), DOYMAZ (2010),

VÁSQUEZ-PARRA *et al.* (2013), JUNQUEIRA *et al.* (2017) and ADILETTA *et al.* (2016a,b; 2018) that found higher rehydration capacity during the rehydration experiments, when different pre-treatments were used to preserve the food structure during drying. On the contrary, some studies have mentioned that an increment of rehydration capacity of dried fruits such as for hawthorn (ARAL and MEŞE, 2016), apple (DOYMAZ, 2010; ZURA-BRAVO *et al.*, 2013), red pepper (VEGA- GALVEZ *et al.*, 2008) and lemon (WANG *et al.*, 2018) was observed by increasing the rehydration temperature. This because the higher rehydration temperatures cause the tissue collapse and cell damage, creating larger spaces in dried fruits and in this way enhancing the rehydration ability of the dried materials (WANG *et al.*, 2018).

In Tables 1 and 2, the rehydration quality indices (WAC, DHC, RA and WHC) of both TR and UTR dried apples (50°, 55°, 60° and 65°C) at rehydration temperatures of 30° and 70°C, respectively, were reported. At 30°C, the WAC and DHC indices showed significantly ($p<0.05$) higher values for treated samples dried at 60° and 65°C. This trend indicates that the treated samples were able to absorb more water at low rehydration temperature with regard to the untreated ones. Similar findings were reported by Barrera *et al*. (2016), which found higher values of WAC and DHC indices in rehydrated apples treated previously with vacuum impregnation with sucrose solution. They stated that these higher indices are correlated to higher rehydration ability of apple samples. Furthermore, the highest ability to rehydrate (RA index) and the highest WHC values were observed in treated samples dried at 60° and 65°C and rehydrated at 30°C. Accordingly, increasing rehydration temperature (70°C) leads to texture damage likely due to the fact that the breaking or the denaturation of polysaccharides of cell wall promotes a remarkable reduction of mechanical resistance in the apples. Similar WHC results were obtained by ZURA-BRAVO *et al.* (2013), which found that the highest rehydration temperature (60°C) resulted in lower WHC of rehydrated apple slices.

Table 1. Rehydration indices of both untreated (UTR) and treated (TR) dried samples (50°, 55°, 60° and 65°C) at rehydration temperatures of 30°C.

Rehydration at 30°C	WAC	DHC	RA	WHC
UTR 50°C	0.781 ± 0.03^{a}	0.233 ± 0.007^{a}	0.182 ± 0.02^{a}	0.794 ± 0.013^{a}
TR 50°C	0.806 ± 0.02^{ab}	0.243 ± 0.004^{a}	0.196 ± 0.009^{ab}	0.822 ± 0.02^{ab}
UTR 55°C	0.784 ± 0.024^{a}	0.240 ± 0.008^{a}	0.188 ± 0.005^{ab}	0.796 ± 0.06^{a}
TR 55°C	0.827 ± 0.03^{ab}	0.247 ± 0.003^{a}	0.204 ± 0.014^{ab}	0.859 ± 0.002^{abc}
UTR 60°C	0.816 ± 0.014^{ab}	0.241 ± 0.005^{a}	0.197 ± 0.03^{ab}	0.844 ± 0.03^{abc}
TR 60°C	0.847 ± 0.02^{b}	0.268 ± 0.003^{b}	0.227 ± 0.02^{ab}	0.902 ± 0.015^{c}
UTR 65°C	0.831 ± 0.02^{ab}	0.243 ± 0.006^{a}	0.202 ± 0.009^{ab}	0.877 ± 0.02^{bc}
TR 65°C	0.853 ± 0.013^{b}	0.274 ± 0.004^{b}	0.234 ± 0.012^{b}	0.911 ± 0.02^{c}

Data are the average of three replicates±standard deviation. Different superscript letters in the same column mean significant differences ($p<0.05$).

BARRERA *et al.* (2016) revealed that the vacuum impregnation (VI) with an isotonic sucrose solution significantly improved rehydration process of apple. This explanation was confirmed by higher values of WAC, DHC and WHC reached by VI sucrose samples.

After rehydration experiments at higher temperature 70°C, no significant differences ($p>0.05$) were found in the following indices: DHC, RA, WHC between all untreated and treated samples; except for the treated samples dried at 60°C which showed the highest WAC value.
The combination of lower rehydration temperature (30°C) and higher drying temperatures (60° and 65°C) with this pre-treatment was proven to be useful to preserve the rehydrated apple structure by reducing cellular damage and promoting the absorption of great amount of water.

Table 2. Rehydration indices of both untreated (UTR) and treated (TR) dried samples (50°, 55°, 60° and 65°C) at rehydration temperature of 70°C.

Rehydration at 70°C	WAC	DHC	RA	WHC
UTR 50°C	0.767 ± 0.02^{a}	0.222 ± 0.02^{a}	0.177 ± 0.005^{a}	0.807 ± 0.02^{a}
TR 50°C	0.811 ± 0.023^{ab}	0.236 ± 0.003^{a}	0.191 ± 0.012^{a}	0.825 ± 0.02^{a}
UTR 55°C	0.799 ± 0.03^{ab}	0.213 ± 0.003^{a}	0.170 ± 0.02^{a}	0.813 ± 0.14^{a}
TR 55°C	0.822 ± 0.02^{ab}	0.237 ± 0.02^{a}	0.195 ± 0.03^{a}	0.823 ± 0.03^{a}
UTR 60°C	0.801 ± 0.02^{ab}	0.218 ± 0.014^{a}	0.181 ± 0.02^{a}	0.821 ± 0.02^{a}
TR 60°C	0.830 ± 0.01^{b}	0.241 ± 0.02^{a}	0.200 ± 0.003^{a}	0.870 ± 0.015^{a}
UTR 65°C	0.790 ± 0.015^{ab}	$0,240\pm0.02^{a}$	0.190 ± 0.004^{a}	0.843 ± 0.009^{a}
TR 65°C	0.817 ± 0.01^{ab}	0.239 ± 0.01^{a}	0.195 ± 0.008^{a}	0.879 ± 0.005^{a}

Data are the average of three replicates±standard deviation. Different superscript letters in the same column mean significant differences ($p<0.05$).

3.2. Diameter and thickness evolution

Diameter and thickness evolution is another important factor that should be analyzed during the rehydration tests of apples.
The average diameter and thickness of all dried apples were evaluated during the rehydration. All samples had similar increasing trend of the diameter and thickness during the experiments at 30° and 70°C. In Figs. 3A-B and 4A-B the diameter and thickness of UTR and TR samples dried at 65°C were compared. In all the conditions investigated, they did not reach the diameter and thickness of fresh samples, which were respectively 30 mm and 5 mm.
Obviously, the fastest increment of diameter and thickness took place in the initial period of the rehydration process. In the further stage of process, water absorption slowed down since rehydrated samples got close to the state of balance with equilibrium moisture content.
There were significant increments of diameter and thickness of both samples (TR and UTR) up to 120 min of the rehydration process (for 30° and 70°C). Higher increases in diameter and thickness were observed in treated samples than untreated ones at both temperatures: at 30°C the recovered volume (with respect to fresh one) of TR samples was 78% while that of UTR samples was 71%. In additon, Table 3 showed the diameter and thickness values of untreated (UTR) and treated (TR) apple samples dried at 65°C reached at the end of rehydration step at 30° and 70°C. The final diameter values were significantly different from each other. The '65 TR 30°C' sample exhibited higher diameter than the samples '65 UTR 30°C', '65 UTR 70°C', and '65 TR 70°C'.

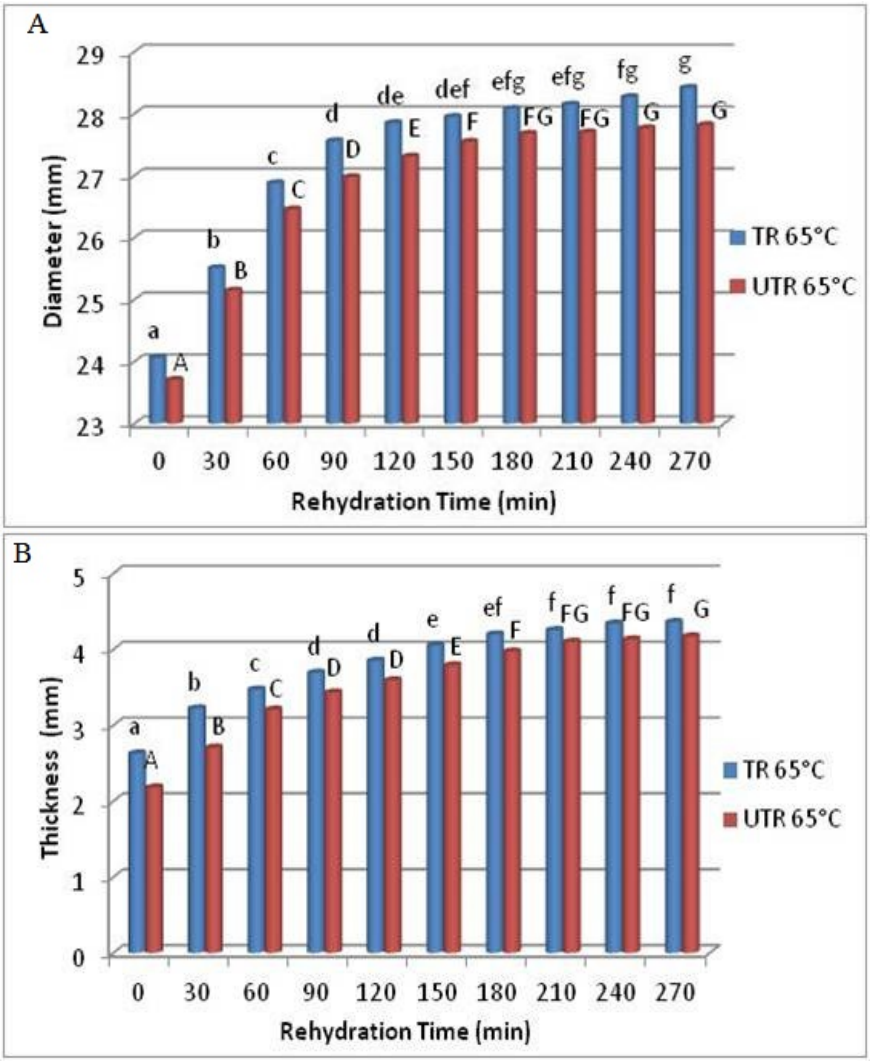

Figure 3. Diameter (A) and thickness (B) of untreated (UTR) and treated (TR) rehydrated samples dried at 65°C during rehydration at 30°C.
Mean values in treated samples with different lower letters are significantly different ($p<0.05$) during the rehydration time, and mean values in untreated samples column with different capital letters are significantly different ($p<0.05$) during the rehydration time.

These results indicated that the pre-treatment solution and rehydration temperature had great impact on final size, shape and appearance of apple samples, therefore on the consumer acceptability. Similarly, in concern with final thickness, no significant differences were found between the samples '65 UTR 70°C' and '65 TR 70°C', while the'65 TR 30°C' sample had the highest final thickness values. Such behaviour is probably due to use of dissacharides, particularly trehalose which effect on pectic cell components results mainly on protecting functionality of proteins and stabilisng the three-dimensional structure of protein (LEWICKI, 1998). In this way, the cell membrane is protected and upon rehydration its functionality is restored. The structure changes and loss of nutritional compounds in untreated samples may be associated with the observation of crack internally in the later stages of rehydration at 70°C. Moreover, the diameter changes were more significant than thickness ones in all investigated samples because the

shrinkage due to the drying occurs preferentially along the diameter than the thickness of the slabs. Among the two investigated temperatures, the best temperature was 30°C with regards to the increment of diameter-thickness of samples.

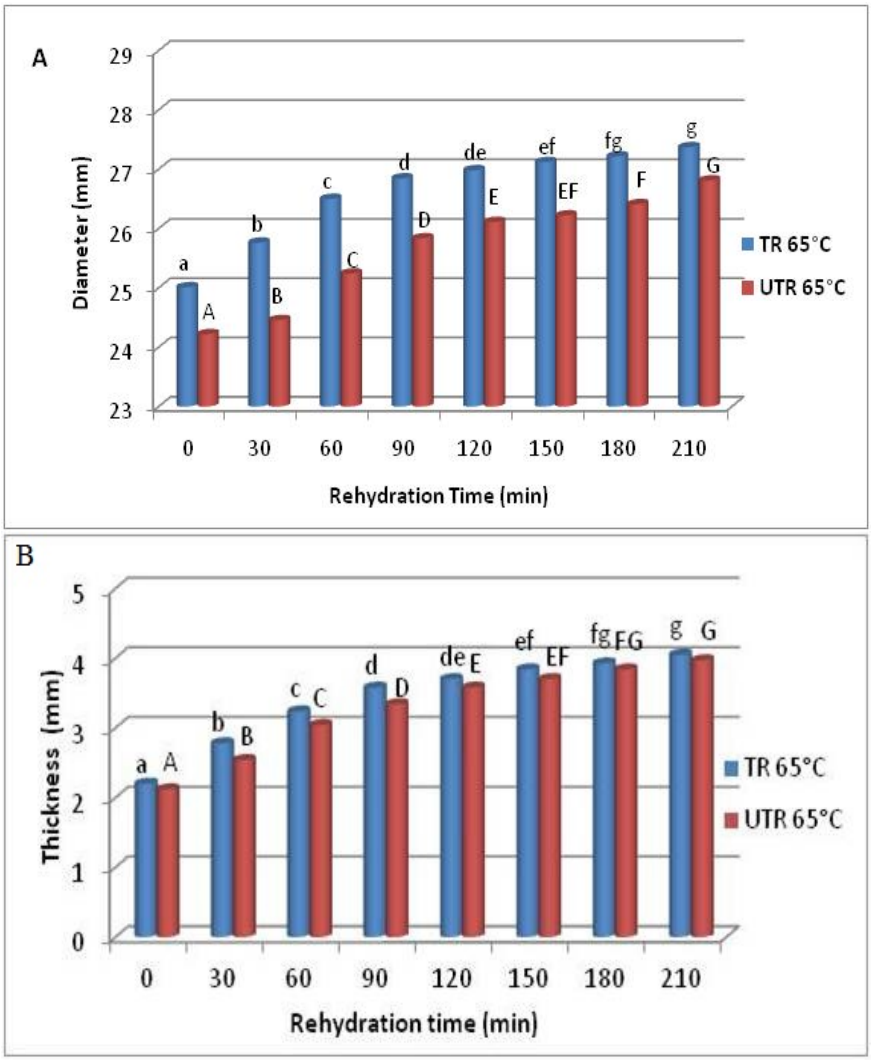

Figure 4. Diameter (A) and thickness (B) of untreated (UTR) and treated (TR) rehydrated samples dried at 65°C during rehydration at 70°C.
Mean values in treated samples with different lower letters are significantly different ($p<0.05$) during the rehydration time, and mean values in untreated samples column with different capital letters are significantly different ($p<0.05$) during the rehydration time.

The ability to be reconstituted of food products depends especially on the inner structure of the dehydrated samples. The rehydration temperature increament induces a structural damage, increasing that caused during the dehydration process. Moreover, increasing temperature results in low mechanical resistance and elasticity in the products. It is seen that, treated apples have homogenous structure which is protected by the pre-treatment and upon rehydration its functionally is restored. This maybe be attributed to the trehalose solution which replaces water in membrane and prevent the phase transition in dried apples. Moreover, trehalose is able to form glassy matrices, and direct the sugar

interaction with polar groups in phospholipids and proteins, thereby maintaining and stabilizing cellular structure (CROWE *et al.*, 1988; LEWICKI, 1998; BETORET *et al.*, 2015).
Several studied investigated the impact of pre-treatments and of drying/rehydration conditions on the dimension changes of dried fruit and vegetable during their rehydration. WINICZENKA *et al.* (2014) found that the temperature of drying influenced the relative increase of the volume of dried apples during rehydration at 20°C.
According to BILBAO-SÁINZ *et al.* (2005), apple cylinders dehydrated in microwave oven with vacuum impregnation showed that the recovered volume (%) of impregnated samples was higher than the recovered volume of non-impregnated ones. A justification to this result is that the major part of the initial gas (air) present in the pores is released by vacuum impregnation and entrance of the isotonic solution of the apple juice in the pores increases the mass of sample.

Table 3. Final diameter and thickness values of untreated (UTR) and treated (TR) rehydrated samples dried at 65°C during rehydration at 30° and 70°C.

Sample	Diameter (mm)	Thickness (mm)
65 UTR 30°C	27.82±0.05^{c}	4.17±0.04^{b}
65 UTR 70°C	26.81±0.05^{a}	3.97±0.04^{a}
65 TR 30°C	28.42±0.05^{d}	4.36±0.04^{c}
65 TR 70°C	27.37±0.05^{b}	4.05±0.04^{a}

3.3. Colour evaluation

Colour parameters are also important as quality indices for rehydrated food products and they should closely resemble the colour characteristics of fresh food material to increase consumer acceptability (COX *et al.*, 2012). The evaluation of rehydration conditions with the aim of minimizing the colour changes during drying/rehydration process is crucial from an economic perspective. The effects of pre-treatment and drying/rehydration temperatures on colour parameters of fresh and rehydrated apple slabs were presented in Table 4. Lightness (L*) and white index (WI) were reported. According to results, the colour values of rehydrated apple slabs were significantly different ($p<0.05$) in relation to fresh ones. It was observed a decrease in L* and WI values in all samples, indicating a reduction of lightness respect to fresh ones. This is an unexpected result since it is believed that an increase in water gain would normally lead to a higher luminosity (GOWEN *et al.*, 2006; MOREIRA *et al.*, 2008). Based on these results, it is argued that some modifications in the optical properties of the apples occurred during the rehydration. Oxidation processes or other chemical reactions such as Maillard reactions probably led to formation of browning agents (GOWEN *et al.*, 2006; MOREIRA *et al.*, 2008; LEMUS-MONDACA *et al.*, 2009; DENG *et al.*, 2017). Treated rehydrated samples had higher L* and WI values than untreated rehydrated ones at both rehydration temperatures (30° and 70°C), demonstrating that the pre-treatment preserves the colour stabilization of the final rehydrated apples. Furthermore, drying temperatures have a key role on colour attributes of dried products, as well as of rehydrated foodstuffs (LINK *et al.*, 2017). The higher drying temperature resulted in the best colour preservation in terms of lightness and white index at both rehydration temperatures. On the contrary, MOREIRA *et al.* (2008) and

ZURA-BRAVO *et al*. (2013) for rehydrated chestnut and apples, respectively, showed a reduction of L* values when the rehydration temperature increased.
As a consequence, the pre-treatment combined with higher drying temperatures (60° and 65°C) had significant effect on colour of rehydrated samples, while both used rehydration temperatures did not significantly influence the colour changes of rehydrated slabs.

Table 4. Colour parameters for untreated (UTR) and treated (TR) fresh and rehydrated samples (drying temperatures, 50°, 55°, 60° and 65°C) at rehydration temperatures 30° and 70°C.

Samples	L*	WI
Fresh Apples		
UTR Fresh	81.73±0.66^{f}	72.13±1.79^{g}
TR Fresh	84.79±2.89^{f}	76.91±1.02^{h}
Rehydrated Apples at 30°C		
UTR 50°C	53.26±1.97^{a}	45.30±2.00^{a}
TR 50°C	60.45±1.15^{bc}	59.48±1.31^{cde}
UTR 55°C	53.59±1.29^{a}	46.82±0.59^{a}
TR 55°C	65.98±0.77^{de}	58.31±0.90^{cd}
UTR 60°C	57.64±1.53^{ab}	45.68±0.89^{a}
TR 60°C	66.31±0.62^{de}	62.09±0.34^{ef}
UTR 65°C	59.15±2.79^{bc}	52.55±1.52^{b}
TR 65°C	66.81±0.25^{de}	62.88±1.60^{ef}
Rehydrated Apples at 70°C		
UTR 50°C	57.55±2.15^{ab}	56.25±1.93^{bc}
TR 50°C	65.51±1.71^{de}	62.57±0.31^{def}
UTR 55°C	59.35±0.61^{bc}	57.27±0.53^{c}
TR 55°C	65.39±0.55^{de}	64.74±1.61^{f}
UTR 60°C	62.77±1.59^{cd}	59.71±0.51^{cde}
TR 60°C	66.12±0.80^{de}	66.01±1.23^{f}
UTR 65°C	60.31±0.50^{bc}	58.13±1.38^{cd}
TR 65°C	68.13±0.18^{e}	65.75±1.83^{f}

Values are expressed as mean±standard deviation. All measurements are performed in triplicate. Values with different letters in a given column are significantly different ($p<0.05$).

3.4. DPPH radical scavenging activity

The knowledge of the content and stability of apple antioxidant components after rehydration treatments is essential to assess the nutritional values prior to its consumption (COX *et al.*, 2012). The radical scavenging activity for all analyzed samples was showed in Fig. 5 at the two rehydration temperatures (30° and 70°C). As expected, the lowest EC_{50} values (the highest antioxidant activity) were found as 16.06 and 18.66 mg/mL db in TR and UTR fresh samples, respectively.
Antioxidant activity of all untreated and treated rehydrated samples decreased after both rehydration processes at 30° and 70°C. For treated apples rehydrated at 30°C the DPPH activity was higher than those at 70°C. The pre-treatment combined with the lower drying

temperatures (50° and 55°C) and the lower rehydration temperature (30°C) can better protect the antioxidant activity of rehydrated apple slabs. The possible explanation of this trend is that during the drying and rehydration processes at higher temperatures modifications of the chemical structure of the main antioxidant compounds in apple (i.e., chlorogenic acid, quercetin, gallic acid, α- tocopherol) or interactions between antioxidant compounds and other apple constituents, such as proteins occurred (ÖNAL *et al.*, 2019). In addition, trehalose – dried and rehydrated foods showed a higher nutritional value with respect to foods processed by conventional system (COLAÇA and ROSER, 1994). In this case, lower rehydration temperature (30°C) had positive effect on the radical scavenging activity of rehydrated apples: higher water temperatures promoted significant loss of antioxidant compounds also into the water. Similar findings were stated by MOLDANADO *et al.* (2010), which reported that increases in temperature above 40°C resulted in higher loss of solid compounds.
In contrast to these results, COX *et al*. (2012) evaluated the influence of the rehydration temperatures (20°, 40°, 60°, 80° and 100°C) on the antioxidant activity of seaweed. They reported that the seaweed rehydrated at 80°C showed the highest antioxidant activity increment. Higher rehydration temperatures positively effect on the DPPH activity of seaweeds.
ZURA-BRAVO *et al.*, (2013) also found a higher antioxidant activity of rehydrated apple slices (*Granny Smith*) at 60°C rather than 20 and 40°C. This increment at higher rehydration temperature is attributed to the accumulation of melanoidins from Maillard reaction which have different antioxidant activity values. Hence, the higher rehydration temperature promoted the penetration of water, thus resulting in a high antioxidant activity (MIRANDA *et al.*, 2009; VEGA-GÁLVEZ *et al.*, 2009).

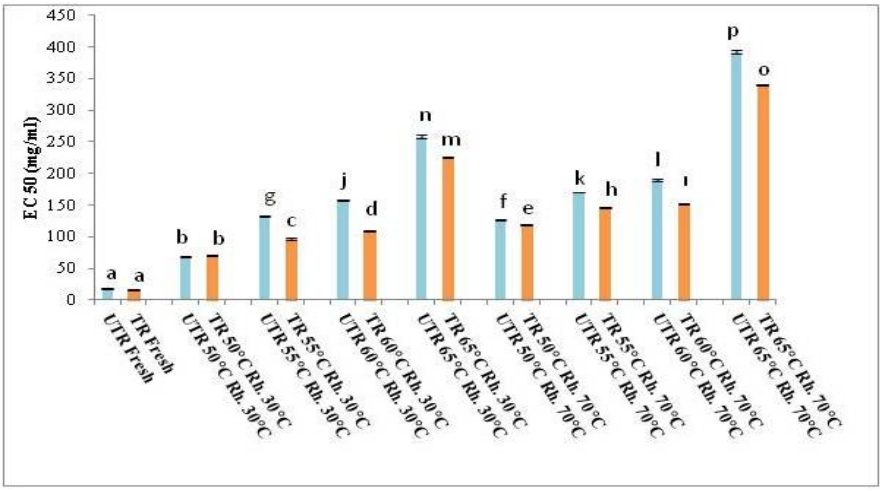

Figure 5. Antioxidant activity of both untreated (UTR) and treated (TR) fresh and rehydrated apples (drying temperature: 50°, 55°, 60° and 65°C) at 30°C and 70°C.

3.5. Effect of pre-treatment, drying/rehydration temperatures by PCA

The effect of pre-treatment and drying/rehydration temperatures on the qualitative traits of rehydrated apples were evaluated by PCA analysis. Covariance matrix showed that the eigenvalues accounted for 67.63% of the total variance in the dataset using two principal

components (PCs). PC1 explained 38.52% of the variance in the dataset, whereas PC2 explained an additional 29.11% of the variance. All loadings and scores were shown in the same PCA plot (Fig. 6).
WAC (R^2= 0.844), DHC (R^2=0.851), RA (R^2= 0.831), WHC (R^2= 0.590) were positively correlated to PC1; while L* (R^2= 0.807), WI (R^2=0.876), EC50 (R^2=0.585) indicated a positive correlation to PC2.
As shown in PCA plot, according to the rehydration temperature of 30°C, treated slabs dried at 50° and 55°C are more similar than those dried at 60° and 65°C. Furthermore, those dried at 60° and 65°C were more correlated with quality parameters in terms of WAC, DHC, RA and WHC along PC1, indicating that the drying temperature had significant impact on the ability to reconstitute the water content of apples during rehydration process. At the same rehydration temperature (30°C), untreated apples dried at 50° and 55°C were closer to each other than untreated apples dried at 60° and 65°C. As it is seen from Fig. 6, these latter (UTR dried at 60° and 65°C) were more correlated with quality parameters of rehydrated apples along PC2, i.e, colour parameters. It is clear that the higher drying temperatures (60° and 65°C) showed the better rehydration results in both UTR and TR apples.
With regard to the rehydration temperature of 70°C, treated dried samples at 50°, 55° and 60°C were similar. Scoring and loading plot enabled to differentiate the behaviour only for treated apples dried 65°C which were more correlated with PC2.
Untreated samples rehydrated at 70°C shifted from negative values to positive ones along PC2.
In conclusion, higher rehydration temperature (70°C) negatively affected quality parameters of rehydrated apples. The samples rehydrated at 30°C showed the better correlations with quality parameters.

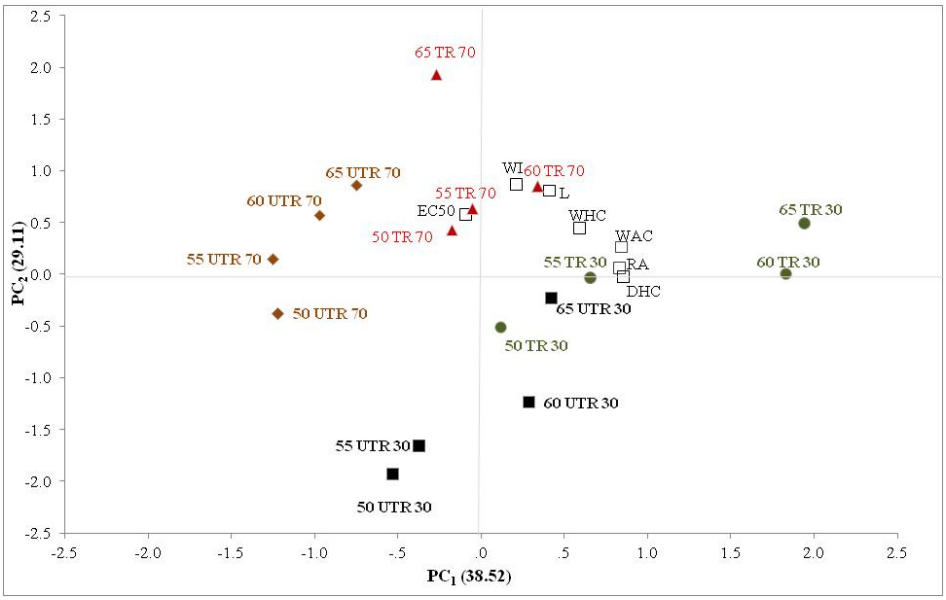

Figure 6. Two-dimensional principal component analysis of rehydration properties for untreated (UTR) and treated (TR) samples dried at 50°, 55°, 60° and 65°C and rehydrated at 30° and 70°C. (WI = white index; L= lightness; WAC = water absorption capacity; DHC = drying matter holding capacity; RA = rehydration ability; WHC = water holding capacity; EC50 = antioxidant activity).

4. CONCLUSIONS

The investigation of drying/rehydration process conditions and of an alternative dipping pre-treatment on the rehydration curves and qualitative traits of rehydrated 'Annurca' apple slabs, has shown valuable findings related to keeping quality of apples. Rehydration temperatures (30° and 70°C) did not significantly affect the weight gain of dried apples. On the other hand, lower rehydration temperature (30°C) with the pre-treatment had positive effect on the rehydration indices (WAC, DHC, RA and WHC). Higher increases in volume were observed in treated rehydrated samples in comparison with the untreated ones. The pre-treatment was able to preserve the colour properties at both rehydration temperatures, while the lower the drying temperature and the lower rehydration temperature, the higher antioxidant activity for both samples was measured. The results clearly highlighted that the rehydration process and quality of rehydrated apples are influenced by pre-treatment, drying and rehydration temperatures. The combination between dipping pre-treatment with trehalose and optimal drying temperature (65°C) at lower rehydration temperature (30°C) allowed to obtain the best overall reconstitution properties of the rehydrated apples in terms of the rehydration characteristics and structure. Thereby, it is recommended to combine the natural pre-treatment and those drying/rehydration process conditions to achieve the high quality attributes of dried/rehydrated apples to meet consumer expectation. These findings, combined with sensorial analysis with trained panel, will contribute to industrial applications and to literature information on the quality attributes of rehydrated apples. Thus, the understanding and characterisation of rehydration process make it a potential research area for designing of new and higher value - added products.

REFERENCES

Adiletta G., Wijerathne C., Senadeera W., Russo P., Crescitelli A. and Di Matteo M. 2018. Dehydration and rehydration characteristics of pretreated pumpkin slices. Italian J. Food Sci. 30(4):684-706. DOI: doi.org/10.14674/IJFS-1176

Adiletta G., Russo P., Senadeera W. and Di Matteo M. 2016a. Drying characteristics and quality of grape under physical pretreatment. J. Food Eng. 172:9-18. DOI: doi.org/10.1016/j.jfoodeng.2015.06.031

Adiletta G., Russo P., Crescitelli A. and Di Matteo M. 2016b. Combined pretreatment for enhancing quality of dried and rehydrated eggplant. Food Bioprocess Technol. 9(11):1912-1923. DOI: doi.org/10.1007/s11947-016-1778-y

Adiletta G., Alam M.R., Cinquanta L., Russo P., Albanese D. and Di Matteo, M. 2015. Effect of abrasive pretreatment on hot dried goji berry. Chem. Eng. Trans. 44:127-132. DOI: doi.org/10.3303/CET1544022

Aktas T., Fujii S., Kawano Y. and Yamamamoto S. 2007. Effects of pretreatments of sliced vegetables with trehalose on drying characteristics and quality of dried products. Food Bioprod. Process 85(3):178-183.
DOI: doi.org/10.1205/fbp07037

Amin I., Norazaidah Y.and Emmy Hainida K.I. 2006. Antioxidant activity and phenolic content of raw and boiled, *Amaranthus* species. Food Chem. 94:47-52. DOI: doi:10.1016/j.foodchem.2004.10.048

Aral S., Meşe A.V. 2016. Convective drying of hawtorn fruit (Crataegus spp.): Effect of experimental parameters on drying kinetics, color, shrinkage, and rehydration capacity. Food Chem. 210:577-584. DOI: doi.org/10.1016/j.foodchem. 2016.04.128

Atarés L., Chiralt A. and González-Martínez C. 2008. Effect of solute on osmotic dehydration and rehydration of vacuum impregnated apple cylinders (cv. Granny Smith). J. Food Eng. 89, 49-56. DOI: doi:10.1016/j.jfoodeng.2008.04.002

Baeghbali R., Niakousari M., Ngadi M.O. and Eskandari M.H.2019. Combined ultrasound and infrared assisted conductive hydro-drying of apple slices. Dry Technol. 37(14):1793-1805. DOI: doi.org/10.1080/07373937.2018.1539745

Barrera C., Betaret N. and Betaret P.F. 2016. Calcium and temperature effect on structural damage of hot air dried apple slices: Nonlinear irreversible thermodynamic approach. J. Food Eng. 189:106-44. DOI: doi.org/10.106/j.jfoodeng.2016.05.24

Benseddik A., Azzi A., Zidoune M.N., Khanniche R. and Besembes C. 2019. Empirical and diffusion models of rehydration process of differently dried pumpkin slices. J. Saudi Soc. Agric. Sci. 18:401-410. DOI: doi.org/10.1016/j.jssas.2018.01.003

Betoret E., Betoret N., Castagnini J.M., Rocculi P., Dalla Rosa M. and Fita P. 2015. Analysis by non-linear irreversible thermodynamics of compositional and structural changes occurring during air drying of vacuum impregnated apple (cv. Granny Smith): calcium and trehalose effects. J. Food Eng. 147:95-101. DOI: doi.org/10.1016/j.jfoodeng.2014.09.028

Bilboa-Sáinz C., Andrés A. and Fito, P. 2005. Hydration kinetics of dried apple as affected by drying kinetics. J. Food Eng. 68:369-376. DOI: doi.org/10.1016/j.jfoodeng.2004.06.012

Brand-Williams W., Cuvelier M.E. and Berset C.L.W. 1995. Use of a free radical method to evaluate antioxidant activity. LWT-Food Sci Technol. 28(1):25-30. DOI: doi.org/10.1016/S0023-6438(95)80008-5

Colaço C.A.L.S. and Roser B. 1994. Trehalose- a multifunctional additive for food preservation. Food Packing. Preserv. 123-140. DOI: doi.org/10.1007/978-1-4615-2173-0_7.

Cox S., Gupta S. and Abu-Ghannami N. 2012. Effect of different rehydration temperatures on the moisture, content of phenolic compounds, antioxidant capacity and textural properties of edible Irish brown seaweed. LWT-Food Sci. Technol. 47:300-307. DOI: doi.org/10.1016/j.lwt.2012.01.023

Crowe J.H., Crowe L.M., Carpenter J.F., Rudolph A.S., Winstrom C.A., Spargo B.J. and Anchordoguy T.J. 1998. Interactions of sugars with membranes. BiochimBiophysActa 947(2):367-384. DOI: doi.org/10.1016/0304-4157(88)90015-9

D'Abrosca B., Scognamiglio M., Corrado L., Chiocchio I., Zampella L., Mastrobuoni F., Rega P., Scortichini M., Fiorentino A. and Petriccione M., 2017. Evaluation of different training system on Annurca apple fruits revealed by agronomical, qualitative and NMR-based metabolomi approaches. Food Chem. 222:18-27. DOI: doi.org/10.106./j.foodchem.2016.11.144

Da Costa Ribeiro A.S., Aguiar-Oliveira E. and Maldonado R.R., 2016. Optimization of osmotic dehydration of pear followed by conventional drying and their sensory quality. LWT-Food Sci. Technol. 72:407-415. DOI: doi.org/10.1016/j.lwt.2016.04.062

Dermesonlouoglou E.K., Giannakourou M.C. and Taoukis P. 2007. Stability of dehydrofrozen tomatoes pretreated with alternative osmotic solutes. J. Food Eng. 78:272-280. DOI: doi.org/10.1016/j.jfoodeng.2005.09.026

Doymaz I. 2010. Effect of citric acid and blanching pre-treatments on drying and rehydration of Amasya red apples. Food Bioprod Process 88(2-3):124-132. DOI:doi.org/10.1016/j.fbp.2009.09.003

Doymaz I. 2007. Air-drying characteristics of tomatoes. J. Food Eng. 78:1291-1297. DOI: doi.org/10.1016/j.jfoodeng.2005.12.047

García-Pascual P., Sanjuán N., Melis R. and Mulet A. 2006. Morchella esculenta (morel) rehydration process modeling. J. Food Eng. 72(4):346-353. DOI: doi.org/10.1016/j.jfoodeng.2004.12.014

Junqueira J.R.J., Correra J.L.G., Oliveira H.M. Avelar R.I.S. and Pio L.A.S. 2017. Convective drying of cape gooseberry fruits: Effect of pretreatments on kinetics and quality parameters. LWT- Food Sci. Technol. 82:404-410. DOI: doi.org/10.1016/j.lwt.2017.04.072.

Krokida M.K. and Marinos-Kouris D. 2003. Rehydration kinetics of dehydrated products. J. Food Eng. 57:7-1. DOI: doi.org/10.1016/S0260-8774(02)00214-5

Krokida M.K., Karathanos V.T. and Maroulis Z.B. 2010. Compression analysis of dehydrated agricultural products. Dry Technol. 18:395-408. DOI: doi.org/10.1080/07373930008917711

Lewicki P.P. 1998. Effect of pre-drying treatment, drying and rehydration on plant tissue properties: A review. Internat J. Food Prop. 1(1):1-22. DOI: doi.org/10.1080/10942919809524561

Link J.V., Tribuzi G. and Laurindo J.B. 2017. Improving quality of dried fruits: A comparison between conductive multi-flash and traditional drying methods. LWT- Food Sci. Technol. 84:711-725. DOI: doi.org/10.1016/j.lwt.2017.06.045

Lo Scalzo R., Testoni A. and Genna A. 2001. "Annurca" apple fruit, a Southern Italy apple cultivar textural properties and aroma composition. Food Chem. 73:333-343. DOI: doi.org/10.1016/S0308-8146(00)00306-X

Lopez-Quiroga E., Prosapio V., Fryer P., Norton I.T. and Bakalis S., 2019. A model-based study of rehydration kinetics in freeze-dried tomatoes. Energy Procedia 161:75-82. DOI: doi.org/doi:10.1016/j.egypro.2019.02.060

Maldonado S., Arnau E. and Bertuzzi M.A. 2010. Effect of temperature and pretreatment on water diffusion during rehydration of dehydrated mangoes. J. Food Eng. 96:333-341. DOI: doi.org/10.1016/j.jfoodeng.2009.08.017

Moreira R., Chenlo F., Chaguri L. and Fernandes C. 2008. Water absorption, texture and colour kinetics of air-dried chestnuts during rehydration. J. Food Eng. 86:584-594. DOI: doi.org/10.1016/j.jfoodeng.2007.11.012

Ohtake S. and Wang Y.J. 2011. Trehalose: current use and future applications. J. Pharm. Sci. 100(6): 220-223.DOI: doi.org/10.1002/jps.22458

Önal B., Adiletta G., Crescitelli A., Di Matteo M. and Russo P., 2019. Optimization of hot air drying temperature combined with pre-treatment to improve physico-chemical and nutritional quality of 'Annurca' apple. Food Bioprod. Process 115:87-99. DOI: doi.org/10.1016/j.fbp.2019.03.002

Patist A. andZoerb H. 2005. Preservation mechanisms of trehalose in food and biosystems. Colloids Surf. B: Biointerfaces 40:107-113. DOI: doi.org/10.1016/j.colsurfb.2004.05.003

Ponkham K., Meeso N., Soponronnarit S. and Siriamornpun S. 2012. Modeling of combined far-infrared radiation and air drying of a ring shaped-pineapple with/without shrinkage. Food Bioprod. Process 90:155-164. DOI: doi:10.1016/j.fbp.2011.02.008

Proietti N., Adiletta G., Russo P., Buonocore R., Mannina L., Crescitelli A. and Capitani, D. 2018. Evolution of physicochemical properties of pear during drying by conventional techniques, portable-NMR, and modelling. J. Food Eng. 230:82-98. DOI: doi.org/10.1016/j.jfoodeng.2018.02.028

Rojas M.L. and Augusto P.E.D. 2018. Ethanol pre-treatment improves vegetable drying and rehydration: kinetics, mechanism and impact on viscoelastic properties. J. Food Eng. 233:17-27. DOI: doi.org/10.1016/j.jfoodeng.2018.03.028

Russo P., Adiletta G., Di Matteo M., Farina V., Corona O. and Cinquanta L. 2019.Drying kinetics and physico-chemical quality of mango slices. Chem. Eng. Trans. 75:109-114. DOI: doi.org/10.3303/CET1975019

Tunde-Akintude T.Y. 2008. Effect of soaking water temperature and time on some rehydration characteristics and nutrient loss in dried bell pepper. Agri. Eng. Int. E-J- CIGR, Vol X.

Vásquez-Parra J.E., Ochoa-Martínez C.I. and Bustos- Parra M. 2013. Effects of chemical and physical pretreatment on convective drying of cape gooseberry fruits (*Physalis peruviana*). J. Food Eng. 119:684-654. DOI: doi.org/10.1016/j.jfoodeng.2013.06.037

Vega- Gálvez A., Lemus-Mondaca R., Bikbao-Sainz C., Yagnam F. and Rojas A. 2008. Mass transfer kinetics during convective drying of red pepper var. Hungarian (*Capsicum annuum* L.): mathematical modeling and evaluation of kinetic parameters. J. Food Process. Eng. 31(1):120-137. DOI: doi.org/10.1111/j.1745-4530.2007.00145.x

Wallach, R., Traygot, O. And Saguy I.S. 2011. Modeling of rehydration of porous food materials: II. The dual porosity approach. J. Food Eng. 105:416-421. DOI: doi.org/10.1016/j.jfoodeng.2011.01.024

Xin Y., Zhang M. and 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.). J. Food Eng. 119:640-647. DOI: doi.org/10.1016/j.jfoodeng.2013.06.035

Zayas J., 1997. Functionality of proteins in food. Heidelberg: Springer-Verlag.

Zura-Bravo L., Ah-Hen K., Vega- Gálvez A., Garcia-Segovia P. and Lemus-Mondaca R. 2013. Effect of rehydration temperature on functional properties, antioxidant capacity and structural characteristics of apple (*Granny Smith*) slices in relation to mass transfer kinetics. J. Food Process. Eng. 36:559-571. DOI: doi.org/10.1111/jfpe.12018

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