Impact of processing conditions on the kinetic of vitamin C degradation and 2-furoylmethyl amino acid formation in dried strawberries

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ABSTRACT

In this paper, a study on the usefulness of the determination of vitamin C together with indicators of the initial steps of Maillard reaction (2-furoylmethyl amino acid, 2-FM-AA) during the convective drying of strawberries has been carried out for the first time, paying special attention to the kinetics of degradation and formation, respectively, of both parameters. Formation of 2-FM-AA of Lys, Arg and GABA and vitamin C loss increased with time and temperature following, respectively, a zero and first-order kinetics. As supported by its lower activation energy, 2-FM-GABA (55.9 kJ/mol) and 2-FM-Lys + 2-FM-Arg (58.2 kJ/mol) were shown to be slightly more sensible indicators than vitamin C (82.1 kJ/mol). The obtained results, together with a complementary study on the rehydration ability and sensorial attributes of samples, pointed out the suitability of the convective drying system to obtain dried strawberries of high nutritive quality and bioactivity and good consumer acceptance.

Keywords: dried strawberry; kinetic; vitamin C; 2-furoylmethyl amino acids; rehydration ability; sensory evaluation.

Vitamin C degradation follows a first-order kinetic during drying of strawberry
2-FM-AA formation follows a zero-order kinetic during drying of strawberry
2-FM-AA were indicators slightly more sensible than vitamin C
Sensorial quality of dried strawberry was similar to that of freeze-dried samples
Premium quality dried strawberries were obtained by convective drying
1. Introduction

Strawberry (*Fragaria x ananassa*) is one of the most widely consumed fruits in the world because of its pleasant organoleptic characteristics and nutritive value, vitamin C standing out with a content of about 60 mg/100 g fresh weight (Proteggente et al., 2002). Moreover, in a number of studies in the last decades, strawberry consumption has also been related to human health benefits due to their antioxidant, anticancer, anti-inflammatory and anti-neurodegenerative properties (Hannum, 2004; Basu, Rhone, & Lyons, 2010). As in the case of other fruits and vegetables, fresh strawberry availability is limited by its seasonal harvesting and short shelf-life. Therefore, strawberry is subjected to different industrial processes (freezing, drying, etc.) to obtain a number of products that can either directly be consumed, or used as ingredients in a wide variety of foodstuffs such as cookies, cereals, energy bars, dairy products, beverages, jams and jellies.

Among the different processing techniques, dehydration of fruits by convective drying is one of the most popular. The removal of moisture avoids the growth of microorganisms and inhibits the activity of enzymes that can deteriorate the product during storage. Furthermore, drying transforms the fruit into a processed product with different characteristics, making thus easier its transportation and storage at ambient temperature. However, the processing conditions (temperature, air rate, humidity and time) selected in the application of this preservation method might also give rise to physical (shrinkage and hardness, among others) and chemical changes that directly affect the quality of the dehydrated product (Asami, Hong, Barret, & Mitchell, 2003).

Vitamin C is one of the most important chemical indicators when evaluating the drying processing of fruits and vegetables. Degradation of this vitamin depends on
several factors including temperature, oxygen, metal ion catalysis, light, moisture content, etc. Furthermore, the retention of this vitamin in dried products is also assumed as a general indicator of the preservation of other less labile nutrients (Santos & Silva, 2008). One way to avoid excessive losses of this vitamin during processing is by means of the study of its degradation kinetic. In this concern, some authors have reported first-order kinetics to describe this reaction in several processed foods (Lee & Labuza, 1975; McMinn & Magee, 1997). Regarding the dehydration of strawberry, most of the studies available in the literature address the drying kinetic and the effect of processing conditions on the final loss of this vitamin (Asami et al., 2003; Böhm, Kühnert, Rohm, & Scholze, 2006; Wojdylo, Figiel, & Oszmianski, 2009). However, to the best of our knowledge, no studies have previously been reported on the kinetic of vitamin C degradation during strawberry drying.

On the other hand, the low water activity ($a_w$) conditions and the high temperatures and long times of processing make favorable the evolution of Maillard reaction (MR), a non-enzymatic browning reaction that takes place between reducing carbohydrates and free amino groups of amino acids, peptides and proteins, during dehydration of fruits. In this respect, 2-furoylmethyl amino acids (2-FM-AA), derivatives of Amadori compounds formed in the first stages of MR, have been previously described as sensible indicators of the early evolution of MR in several dehydrated fruits and vegetables (Sanz, Castillo, Corzo, & Olano, 2001; Rufián-Henares, García-Villanova, & Guerra-Hernández, 2008; Soria, Corzo-Martínez, Montilla, Riera, Gamboa-Santos, & Villamiel, 2010; Wellner, Huettl, & Henle, 2011; Gamboa-Santos, Soria, Villamiel, & Montilla, 2013b). Evaluation of 2-FM-AA provides very valuable information, as their early detection can prevent advanced stages of the MR in which important losses of nutritive value, mainly associated to the participation of the essential
amino acid lysine in MR, are produced (Corzo-Martínez, Corzo, Villamiel, & del Castillo, 2012).

At the sight of the above exposed, the aim of the present study was to investigate the effect of drying conditions on the kinetic of vitamin C degradation and of 2-FM-AA formation during the convective drying of strawberries. In addition, other quality parameters such as rehydration ability and sensorial properties were also assessed in these samples.

2. Materials and methods

2.1. Strawberry samples

Fresh strawberries (Fragaria x ananassa Duch.) were purchased from a local market in Madrid (Spain). They were stored in the dark at 4 °C for a maximum period of 3 days until dehydration. Fresh samples were washed in tap water to remove external impurities and, previously to convective drying, they were cut into 2.5 ± 0.5 mm thickness slices along their longitudinal axes. The moisture content of raw and dried strawberries was determined at 102 °C until constant weight (AOAC, 1990a). Water activity measurement was carried out in a standardized conductivity hygrometer NOVASINA TH-500 (Air Systems for Air Treatment, Pfäffikon, Switzerland) (Gamboa-Santos et al., 2013b).

2.2. Drying processing

Drying assays were carried out using a computer controlled (Edibon Scada Control and Data Acquisition Software) air tray dryer (SBANC, Edibon Technical
Teaching Units, Spain) which has already been described in detail by Gamboa-Santos, Soria, Fornari, Villamiel, & Montilla (2013c). Briefly, the system consists of a fan unit with air rate control, seven sensors for temperature control and a load cell with four drying trays for automatically monitoring of sample weight. For strawberry drying, assays were carried out at full power and 2-8 m/s air flow rate giving rise to 40-70 °C of temperature inside the drying cabinet (assays A-40, A-50, A-60 and A-70). The selected times were 1, 3, 5 and 7 h. The initial weights of the samples were 76.8 ± 3.2 g and it was automatically monitored by the load cell. All drying experiments were carried out in duplicate. Additionally, strawberry samples processed in a laboratory-scale freeze-drier (LYOBETA-15 de Telstar, Terrassa, Spain) at 20 °C and vacuum pressure 0.020 mbar during two days were used as control.

2.3. Determination of vitamin C

The total vitamin C content (ascorbic acid plus dehydroascorbic acid) of strawberry samples was determined following the method of Gamboa-Santos, Soria, Pérez-Mateos, Carrasco, Montilla, & Villamiel (2013a) by Reversed Phase-High Performance Liquid Chromatography with Diode Array Detection (RP-HPLC-DAD). Separation was carried out under isocratic conditions (flow rate 1 mL/min; 10 min) on an ACE 5 C18 column (ACE, UK) (250 mm length x 4.6 mm i.d. x 5 μm) at 25 °C, using 5 mM KH2PO4 (pH 3.0) as mobile phase.

2.4. Determination of 2-furoylmethyl amino acids
Strawberry hydrolyzate samples were prepared following the method of Gamboa-Santos et al. (2013c). Analysis of 2-FM-AA was carried out by ion-pair RP-HPLC (Resmini & Pellegrino, 1991), in a furosine-dedicated C₈ column (250 mm length x 4.6 mm i.d., Alltech, Lexington, KY) at 37 °C. The linear binary gradient of phase A (4 mL/L acetic acid) and phase B (3 g/L KCl in phase A solution) was as follows: 100% A between 0 and 12 min; 50% A from 20 to 22.5 min; 100% A for 24.5 to 30 min. The flow rate was 1.2 mL/min and detection was done at 280 nm using a variable wavelength detector (LCD Analytical SM 4000).

Additionally, spiking of a commercial standard of 2-FM-Lys (furosine, Neosystem Laboratoire) was used to identify this compound in dried strawberry. The others 2-FM-AA (2-FM-Arg, 2-FM-GABA) were tentatively identified by comparison with standards and hydrolyzates of other vegetables previously analyzed and characterized in our laboratory (del Castillo, Corzo, Gonzalez, & Olano, 1999). Quantitation was performed by the external standard method. Data were expressed as mg/100 g protein and all the analyses were performed in duplicate. Total nitrogen (TN) was determined by the Kjeldahl method (AOAC, 1990b), and the protein content of strawberries was calculated using 6.25 as conversion factor (TN x 6.25).

2.5. Rehydration properties

Strawberry slices were rehydrated in Milli-Q water (solid-to-liquid ratio 1:50) at room temperature for 2 hours. After removing the superficial water with tissue paper, the rehydrated strawberries were weighted. For each rehydration experiment (n = 3), the rehydration ratio (RR) was calculated as follows:

\[
RR = \frac{m_r}{m_d}
\]

(1)
where \( m_r \) and \( m_d \) represent the mass (g) of rehydrated and dehydrated strawberry, respectively.

Determination of soluble solids lost during rehydration (LL) was carried out as follows: 0.5 mL of soak water of each rehydration experiment was dried in a conventional oven at 105 °C for 24 h. The final solid residue was weighted to calculate the percentage of leached solids with respect to the initial weight of dried strawberry.

2.6. Kinetic modeling

In order to predict the changes in the content of 2-FM-AA and of vitamin C during drying of strawberries, the zero and first-order reaction models were respectively applied, assuming previous related studies (de Rafael, Villamiel, & Olano, 1997; McMinn & Magee, 1997). The respective equations for 2-FM-AA formation and vitamin C degradation are shown below,

\[
\frac{dC_1}{dt} = k_1 
\]

\[
-\frac{dC_2}{dt} = k_2 C_2 
\]

where \( C_1 \) is the concentration of 2-FM-AA and \( C_2 \) is the concentration of Vitamin C, at any time \( t \). \( k_1 \) and \( k_2 \) are the reaction rate constants for 2-FM-AA formation and vitamin C degradation, respectively.

The temperature dependency of the reaction rate constants was determined by the Arrhenius-type equation (McMinn & Magee, 1997) (Eq. 4).

\[
k = k_0 \exp \left( -\frac{E_a}{RT} \right)
\]
where $k_0$ is the pre-exponential Arrhenius factor, $E_a$ is the activation energy (kJ/mol), $R$ is the ideal gas constant (kJ mol/K), and $T$ is the temperature (K).

 Parameter estimation and fit of experimental data were calculated using the software Microsoft Excell 2010.

2.7. Sensory evaluation

After drying, strawberry samples were rehydrated in water, milk or yogurt during ten second using a sample:liquid ratio of 1:50. The sensory analyses of these samples were carried out by a taste panel of 19 panelists (8 men and 11 women, 26-49 years old) who were familiarized with organoleptic text. Rehydrated strawberries in each medium were evaluated in a hedonic test comparing convective dried (60 °C, 4 m/s during 5 h) and freeze-dried strawberry samples. The panelists were asked for each sample on texture and taste, and a balanced 8-point hedonic rating was employed for the overall evaluation of samples, where 1 denoted “like very much” and 8 indicated “dislike very much” (Gamboa-Santos et al., 2013a). Also panelists were asked to indicate their preference.

2.8. Statistical analysis

For kinetics of vitamin C degradation and 2-FM-AA formation and for parameter correlations, goodness of fittings was evaluated by means of the correlation coefficient $R$ and the mean relative error ($MRE$) calculated from Eq. (5).
where $W_{ei}$ and $W_{ci}$ are the experimental and calculated average moisture contents and $N$ is the number of experimental data.

To evaluate differences among samples, including sensory evaluation, data were subjected to one-way analysis of variance (Fisher’s Least Significant Difference Test) by applying the Statgraphic 5.0 program (Statistical Graphics Corp., Rocville, MD). The significance of differences was defined as $p < 0.05$.

3. Results and Discussion

3.1. Drying kinetic

Fig. 1 shows the drying curves obtained during the processing of strawberries by convection as explained in section 2.2 of Materials and methods. For each assay, this figure illustrates the evolution of the moisture loss up to 7 h of drying. After 3 h of drying, strawberries showed DM contents > 80% in the case of A-70 and A-60 assays and > 75% in A-50 and A-40 experiments; these values were very close to that generally considered for microbiological stability of dried products (85%) (Belitz, Grosch, & Schieberle, 2009). Moreover, strawberry samples presented values of $a_w$ near 0.3 after this time and hardly any change was detected in this parameter during its further processing. In general, it has been described that modifications as non-enzymatic browning can be avoided at $a_w$ below 0.3 (Belitz et al., 2009; Corzo-Martínez et al., 2012) and $a_w$ values lower than 0.210 can also slow down the degradation of different
bioactive compounds (Moraga, Igual, Garcia-Martinez, Mosquera, & Martinez-Navarrete, 2012).

3.2. Degradation of vitamin C

In agreement with other investigations on the deterioration of nutritional quality during food processing, vitamin C was chosen in the present paper as a very sensible and relatively easy-to-measure marker for determination of food quality. The average vitamin C content determined in the raw strawberry samples here analyzed was 590.9 ± 7.4 mg/100 g DM. This value was close to those reported by other authors (635-683 mg/100 g DM, Böhm et al., 2006; 340-680 mg/100 g DM, Wojdylo et al., 2009). Fig. 2 shows the percentages of vitamin C retention (relative to the average raw control) calculated for strawberries processed under the different drying conditions assayed.

Concerning the effect of moisture content on the degradation of vitamin C, the mechanism by which water controls the degradation reaction is very complex and it is dependent on the complexity of the plant tissue, the pre-processing history and, particularly, the specific moisture range (McMinn & Magee, 1997; Santos & Silva, 2008). Thus, in a study on the drying of tomato, Goula and Adamopoulos (2006) found that the reaction rate of ascorbic acid degradation increased with the reduction of moisture content from 95 to 65%. When moisture content reached 65-70%, the rate of this reaction reached a maximum value and at moisture contents below 65%, the rate decreased with moisture reduction. In our assays, when the time of drying was 3 h or higher, a very low moisture content (lower than 65%) was detected in all strawberry samples analyzed, suggesting that, with the exception of the first hour of drying in which the moisture was high, hardly any effect of this parameter on the degradation of vitamin
C can be expected. On the other hand, Santos and Silva (2008) confirmed that at the beginning of the process the effect of moisture content seems to be predominant, while the temperature effect becomes major as the process proceeds. As observed in Fig. 2, the retention of vitamin C was reduced with the time and temperature of drying; this trend was particularly evident at the end of the processes carried out at 60 and 70 °C with retention values of 69 and 40%, respectively. It is also remarkable the high retention of vitamin C (close to 90%) at the mildest temperatures (40 and 50 °C), irrespective of the time of processing. Böhm et al. (2006) observed an ascorbic acid retention of 31-42% with respect to its initial value for strawberries of different varieties (Camarosa, Darselect and Senga Sengana) subjected to a convective drying at 60 °C, 5 m/s during 220 min.). Wojdylo et al. (2009), in a comparative study on several procedures of drying, found a retention of ascorbic acid close to 30% in samples of Elsanta and Kent strawberry dried by convection at 70 °C for 8 h. Serious losses of ascorbic acid content (retention 13-16%) have also been reported after the convective drying of strawberries (Northwest Totem) for a total time of 88 h at 77 °C (short period) and at 49 °C (long period) (Asami et al., 2003). As compared to our data, the differences observed could be due to factors such as strawberry variety, maturity degree, geometry of samples, equipment characteristics and processing conditions, among others.

In order to evaluate the nutritional value of the samples processed in this study, and taking into account that even under the most severe conditions (70 °C, 7 h) an important concentration of vitamin C (233 mg/100 g DM; 40% retention) was preserved, calculation of the minimum amount of dried strawberry required to cover the recommended daily intake (RDI) of this vitamin was done. RDI of vitamin C has been reported to be in the range 40-90 mg (Nutrient reference values for Australia and New Zealand, García-Gabarra, 2006). Therefore, and in absence of other alternative sources,
the necessities of daily intake of vitamin C are fully covered with 21-48 g of dried strawberries (80% DM).

Taking into account the evolution of vitamin C retention during the drying process in the present paper (Fig. 2) and, in agreement with other authors who have studied the kinetic of degradation of this vitamin in dehydrated model systems (Dennison & Kirk, 1978), dried potato (Khraisheh, McMinn, & Magee, 2004), tomato (Goula & Adamopoulos, 2006) and kiwi (Orikasa, Wu, Shiina, & Tagawa, 2008), data were fitted to a first-order kinetic model. The experimental ln C/C₀ versus time representation exhibited linear correlations for each temperature (Fig. S1), with slopes equivalent to the rate constant (k) and correlation coefficients (R) higher than 0.97 (Table 1), suggesting that the model was satisfactory in describing the degradation of vitamin C during convective drying of strawberries. The k values were very low in the case of processes carried out at 40 and 50 °C, indicating that, under these conditions, vitamin C was not as labile as in the other tested temperatures (60 and 70 °C). In a study on starchy food drying, Khraisheh et al. (2004) found k values in the range 0.0016-0.0018 min⁻¹ for ascorbic acid degradation at temperatures 30-60 °C.

With the purpose of gaining insight for the temperature dependence of vitamin C degradation during convective drying of strawberry, Arrhenius correlation was applied and the corresponding activation energy (Eₐ) calculated from the slope of the fitting. The Eₐ value (82.1 kJ/mol) here determined (R = 0.996) was comparable to data previously described by several authors. Lee and Labuza (1975) and Dennison and Kirk (1978) reported values of Eₐ in the wide range 7.5-125.6 kJ/mol for the thermal destruction of ascorbic acid in different dehydrated model systems. Orikasa et al. (2008) investigated the drying characteristics of kiwifruit during hot air drying at temperatures between 40 and 70 °C, and the Eₐ for the decomposition of ascorbic acid was estimated to be 38.6
kJ/mol. The difference between this result and the value of $E_a$ obtained in the present work could be attributed to the different fruit considered, the processing system and geometry of samples, among other factors.

3.3. Formation of 2-furoylmethyl amino acids

The amount of 2-FM-Lys plus 2-FM-Arg (Peak 2 in Fig. S2) determined in strawberries subjected to dehydration increased with the time and temperature and was found to be in the range 35.2-512.1 mg/100 g protein (2.7-38.8 mg/100 g product) for treatments at 40-70 °C for 7 h (Fig. 3a). Sanz et al. (2001) reported values of these parameters in the range 7.7-93.4 mg/100 g product for dehydrated raisins, apricots, dates and figs; the different composition and processing of these fruits could mainly justify the differences observed with respect to strawberry samples. Data for dried strawberries here analyzed were close to those previously reported by Gamboa-Santos et al. (2013c) for blanched carrots dried in the same prototype at 46 °C and an air rate of 4.9 m/s for 7-9 h (104.3-681.5 mg/100 g protein). Considering foodstuffs derived from strawberry, Rada-Mendoza, Olano, & Villamiel. (2002) reported a furosine content of 81.7 mg/100 g protein in strawberry jam. However, the processing of this product is completely different and its $a_w$ noticeably higher (0.919). The formation of 2-FM-GABA (Peak 1 in Fig. S2) followed the same trend as that of the other 2-FM-derivatives previously mentioned, with values between 29.8 and 437.0 mg/100 g protein (2.3-33.1 mg/100 g product) (Fig. 3b). Sanz et al. (2001) reported contents of this quality marker in the range 3.6-75.8 mg/100 g product for dehydrated raisins, apricots, dates and figs.

With respect to the effect of moisture content on 2-FM-AA formation, as above indicated for vitamin C degradation, for a given temperature, the main loss of moisture
was produced before the three first hours of drying and scarce changes were observed after this time. However, a noticeable formation of 2-FM-AA was detected up to the end of the drying assays, especially at 70 °C. Numerous studies have been conducted to address the complex moisture-dependent characteristics of the non-enzymatic browning reactions. Labuza, Tannenbaum, & Karel, (1970) demonstrated that at low (due to limitations of reactants) and high (due to dilution effects) moisture contents the reaction rate decreases. Troller (1989) established “critical moisture contents” for browning to be produced in dehydrated food systems within the $a_w$ range 0.65-0.75. In our assays, after three hours of drying the $a_w$ was close to 0.3 and this value remained almost constant until the end of the process; therefore, it seems that the combination of temperature/time conditions exerts a predominant effect as compared to the $a_w$ in the convective dehydration of strawberries here done.

Data on the formation of 2-FM-Lys plus 2-FM-Arg and of 2-FM-GABA during drying of strawberry samples were adjusted to zero-order reaction models and the rate constants obtained, together with the corresponding determination coefficients and MRE values (Table 1). In general, for all the temperatures assayed, a good fitting of the data was obtained with $R$ higher than 0.97 and MRE values below 12%. As expected, $k$ values for 2-FM-Lys + 2-FM-Arg and for 2-FM-GABA notably increased with temperature and, from the Arrhenius plot, the temperature-dependence of the formation of 2-FM-AA was corroborated. The $E_a$ values calculated from the corresponding Arrhenius equations were 58.2 ($R = 0.94$) and 55.9 kJ/mol ($R = 0.94$) for 2-FM-Lys plus 2-FM-Arg and for 2-FM-GABA formation, respectively. To the best of our knowledge, no previous data have been reported on the kinetic of formation of 2-FM-AA in dried fruits. The only $E_a$ data for furosine formation are those reported by other authors in heated milk (93-104 kJ/mol) (de Rafael et al., 1997), tomato products (94 kJ/mol)
(Hidalgo & Pompei, 2000) and infant formula (113 kJ/mol) (Damjanovic Desic & Birlouez-Aragon, 2011). As in the case of dairy products, where lactose is less reactive to MR than glucose and fructose present in dried strawberries, the different composition of all these food stuffs could justify the higher $E_a$ of furosine reported. With respect to vitamin C degradation, the $E_a$ was higher (82.1 kJ/mol) than those of 2-FM-AA formation. In agreement with $E_a$ values it could be deduced that the latter are slightly more sensible parameters, considering time and temperature, during drying of strawberries in the conditions here assayed.

As it is known, the correlation of diverse quality indicators has shown to be a good tool for the control of several food preservation processes. Taking into account the parameters analyzed in this paper, their correlation can be adequately described by simple linear regressions. Regarding the fitting of experimental data summarized in Table 2, no clear trend associated with temperature could be established between vitamin C loss and 2-FM-AA formation. Rufián-Henares, Guerra-Hernández & García-Villanova (2013) also found a linear correlation (R=0.995) between 2-FM-Lys and ascorbic acid during the dehydration of red sweet pepper in a laboratory rotary evaporator at 60-90 °C for 7.5-45 min.

With respect to the correlation between both 2-FM-AA, a certain trend was observed, since at low temperatures 2-FM-GABA could be as sensible indicator as 2-FM-Lys + 2-FM-Arg and, at high temperatures, the formation of 2-FM-Lys + 2-FM-Arg could be favored over that of 2-FM-GABA.

3.4. Rehydration properties
The rehydration ability of strawberry samples subjected to convective drying was quantified on the basis of the rehydration ratio (\(RR\)) and the leaching losses (\(LL\)) (Table 3). As it can be seen in this table, hardly any change in \(RR\) and \(LL\) were found to be associated with the increase of drying time for any of assayed processing temperatures. The best rehydration properties were observed for A-40 and A-50 assays, with \(RR\) (6.3-7.0) and \(LL\) (59-65.9) values close to those of the freeze-dried samples processed in the laboratory (\(RR\): 6.8; \(LL\): 64). Megías-Pérez, Gamboa-Santos, Soria, Montilla, & Villamiel, (2012), in a survey on several quality indicators in commercial dried fruits, reported \(RR\) values from 4.3 to 6.9 and \(LL\) values in the range 59.7-72.4 g/100 DM for freeze-dried strawberry samples and worse values of these properties for convective dried samples. El-Beltagy, Gamea, & Ammer Essa (2007) also reported lower \(RR\) data (within the range 2.57-3.44) for strawberry samples of different geometries subjected to solar drying for up to 24 h.

As observed in Table 3, assays A-60 and A-70 gave rise to a decrease of the rehydration ability of dried strawberry samples (\(RR = 4.0-5.6; LL = 65.5-72.4\) g/100 g DM). This fact was probably due to the severity of the drying processes carried out under these conditions which could give rise to important structural modifications as compared to freeze-dried strawberry. Radical changes in the structure, with tearing of the cellular walls and part of the tissue as a homogeneous and compact substance, are usually produced during convective drying. In agreement with this, Jokic et al. (2009) reported a decrease of \(RR\) (from 6.9 to 5.9) with the increase of drying temperature (50-70 °C) in dried apples not subjected to any pre-treatment. A similar effect was also described by Vega-Gálvez et al. (2009) in dried peppers processed at 50 and 90 °C, without blanching. As an explanation for this, the damage in cellular structure might result in modification of osmotic properties of the cell as well as in lower diffusion of
water through the surface during rehydration (Kaymak-Ertekin, 2002). It was also reported by these authors that, in general, rehydration rate decreases as the dehydration rate increases. The cellular structure damage would also explain the higher $LL$ determined in samples here analyzed at 60 and 70 °C.

3.5 Sensory evaluation

The sensory evaluation was carried out with freeze-dried and convective strawberry samples dried at 60 °C, 4 m/s during 5 h, since showed high vitamin C retention (76.4%) and low humidity (<15%). As observed in Table 4, all samples presented good marks (2.21-3.63). With respect to taste, the best score (2.21) was found in the freeze-dried sample rehydrated with yoghurt and the worse (3.32) in strawberry sample rehydrated also with yoghurt but dried by convection. Regarding texture, the best mark (2.32) was also the corresponding to freeze-dried strawberry sample rehydrated with yoghurt and the worse (3.63) were both types of samples rehydrated with water. In general, significant differences ($p<0.01$) were only detected for taste and texture between both types of processed samples rehydrated with yoghurt. In this case, the better scores of freeze-dried sample could be due to a higher porosity of this sample in comparison to convective one, whose surface could be more compact due to the microstructural changes produced by the heating.

Taking into account the preference, most of panelist preferred the freeze-dried strawberry sample, indicating that other attributes such as appearance, smell, color, etc. could have influenced the overall scores. However, considering taste and texture, it is possible to say that freeze-dried and convective strawberry samples rehydrated with water and milk were very similar.
4. Conclusions

The kinetic study of vitamin C degradation (first-order) and of 2-FM-AA formation (zero-order) during the drying of strawberry samples, addressed for the first time in this paper, highlights that both parameters are important markers for the quality control of strawberries processed under different operating conditions. According to the $E_a$, 2-FM-AA seem to be slightly more sensible parameters than vitamin C during the drying of strawberry by convection. From a practical point of view, and considering the correlations among indicators here determined, it is possible to carry out for most of drying conditions assayed the determination of one of these quality markers and the estimation of the other from the obtained regressions for strawberries dried under identical conditions. Regarding the rehydration ability, considered in this paper as a complementary quality indicator to nutritional markers (vitamin C and 2-FM-AA), the processing temperature seemed to exert a higher influence than drying time. In a sensorial evaluation, convective strawberry samples presented high scores, similar to freeze-dried samples, particularly in the case of strawberries rehydrated with water and milk. The data here presented afford useful information to the optimization of convective drying of strawberries with the aim to obtain a product with high nutritive quality and bioactivity and good consumer acceptance.

Abbreviations Used:

2-FM-AA: 2-furoylmethyl amino acids

$aw$: water activity
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References


Table 1

Kinetic parameters determined for strawberries convectively dried at 40-70 °C: reaction rate constant ($k$), correlation coefficient ($R$) and mean relative error (MRE) for the fitting of data on vitamin C degradation and 2-FM-AA formation according to first and zero order reactions.

<table>
<thead>
<tr>
<th>Assay</th>
<th>$k_{vit,C}$ (min$^{-1}$)</th>
<th>R</th>
<th>MRE (%)</th>
<th>$k_{2-FM-Lys+2-FM-Arg}$ (mg/100 g protein $\cdot$ min$^{-1}$)</th>
<th>R</th>
<th>MRE (%)</th>
<th>$k_{2-FM-GABA}$ (mg/100 g protein $\cdot$ min$^{-1}$)</th>
<th>R</th>
<th>MRE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-40</td>
<td>-0.00015</td>
<td>0.986</td>
<td>7.97</td>
<td>0.1515</td>
<td>0.965</td>
<td>11.07</td>
<td>0.1561</td>
<td>0.999</td>
<td>2.61</td>
</tr>
<tr>
<td>A-50</td>
<td>-0.00024</td>
<td>0.992</td>
<td>6.48</td>
<td>0.3075</td>
<td>0.994</td>
<td>4.89</td>
<td>0.2825</td>
<td>0.983</td>
<td>11.76</td>
</tr>
<tr>
<td>A-60</td>
<td>-0.00079</td>
<td>0.972</td>
<td>11.29</td>
<td>0.3962</td>
<td>0.995</td>
<td>4.68</td>
<td>0.3428</td>
<td>0.992</td>
<td>6.49</td>
</tr>
<tr>
<td>A-70</td>
<td>-0.00228</td>
<td>0.993</td>
<td>7.08</td>
<td>1.2601</td>
<td>0.994</td>
<td>4.51</td>
<td>1.0698</td>
<td>0.998</td>
<td>2.41</td>
</tr>
</tbody>
</table>
Table 2

Correlation of 2-FM-AA formation and vitamin C degradation in strawberry samples under analysis. Correlation coefficient ($R$) and mean relative error ($MRE$) of the fitting.

<table>
<thead>
<tr>
<th>Assay</th>
<th>2-FM-Lys+2-FM-Arg</th>
<th>R</th>
<th>MRE (%)</th>
<th>2-FM-GABA</th>
<th>R</th>
<th>MRE (%)</th>
<th>2-FM-GABA</th>
<th>R</th>
<th>RME (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-40</td>
<td>-1.52*VitC + 914.80</td>
<td>0.99</td>
<td>2.99</td>
<td>-1.65*VitC + 988.44</td>
<td>0.99</td>
<td>7.31</td>
<td>1.06*(2-FM-Lys + 2-FM-Arg) - 2.60</td>
<td>0.97</td>
<td>10.25</td>
</tr>
<tr>
<td>A-50</td>
<td>-2.17*VitC + 1278.50</td>
<td>0.98</td>
<td>8.24</td>
<td>-2.20*VitC + 1288.13</td>
<td>0.97</td>
<td>14.55</td>
<td>0.99*(2-FM-Lys + 2-FM-Arg) - 8.41</td>
<td>0.97</td>
<td>11.35</td>
</tr>
<tr>
<td>A-60</td>
<td>-0.89*VitC + 519.28</td>
<td>0.98</td>
<td>9.55</td>
<td>-0.82*VitC + 468.80</td>
<td>0.96</td>
<td>14.89</td>
<td>0.91*(2-FM-Lys + 2-FM-Arg) - 7.22</td>
<td>0.98</td>
<td>7.74</td>
</tr>
<tr>
<td>A-70</td>
<td>-1.37*VitC + 819.61</td>
<td>0.99</td>
<td>6.68</td>
<td>-1.20*VitC + 707.74</td>
<td>0.99</td>
<td>3.32</td>
<td>0.87*(2-FM-Lys + 2-FM-Arg) - 7.67</td>
<td>0.99</td>
<td>3.28</td>
</tr>
</tbody>
</table>
Table 3

Rehydration ratio (RR) and leaching losses (LL) (average ± SD, n = 3) of strawberry samples under analysis.

<table>
<thead>
<tr>
<th>Assay</th>
<th>Drying time (h)</th>
<th>RR</th>
<th>LL (g/100 g DM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-40</td>
<td>3</td>
<td>6.3 ± 0.3&lt;sup&gt;d&lt;/sup&gt;</td>
<td>65.9 ± 2.1&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>6.7 ± 0.3&lt;sup&gt;de&lt;/sup&gt;</td>
<td>62.0 ± 2.7&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>6.6 ± 0.4&lt;sup&gt;de&lt;/sup&gt;</td>
<td>60.7 ± 2.9&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>A-50</td>
<td>3</td>
<td>6.4 ± 0.4&lt;sup&gt;de&lt;/sup&gt;</td>
<td>59.9 ± 3.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>6.8 ± 0.3&lt;sup&gt;c&lt;/sup&gt;</td>
<td>62.4 ± 0.2&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>7.0 ± 0.3&lt;sup&gt;c&lt;/sup&gt;</td>
<td>59.0 ± 5.1&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>A-60</td>
<td>3</td>
<td>4.4 ± 0.2&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>70.2 ± 2.8&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4.4 ± 0.2&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>70.4 ± 4.5&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>4.6 ± 0.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>65.5 ± 4.9&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>A-70</td>
<td>3</td>
<td>5.6 ± 0.3&lt;sup&gt;c&lt;/sup&gt;</td>
<td>72.1 ± 3.4&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4.0 ± 0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>70.5 ± 2.4&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>4.2 ± 0.3&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>72.4 ± 1.1&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>1</sup> Samples with the same superscript letter within the same column showed no statistically significant differences for their mean values at the 95.0% confidence level.
Table 4

Sensory scores for quality attributes of strawberry sample dehydrated at 60 °C for 5 h and 4 m/s and freeze-dried.

<table>
<thead>
<tr>
<th>Rehydration medium</th>
<th>Convective dried</th>
<th>Freeze-dried</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Taste</td>
<td>Texture</td>
</tr>
<tr>
<td>Water</td>
<td>2.84 ± 1.17&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.63 ± 1.26&lt;sup*a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Milk</td>
<td>3.17 ± 1.34&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.17 ± 1.34&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Yoghurt</td>
<td>3.32 ± 1.06&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.16 ± 1.26&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> Samples with the same superscript letter within the same file and same attribute showed no statistically significant differences for their mean values at the 99.0% confidence level.
Fig. 1. Drying curves for strawberry samples processed at temperatures in the range 40-70 °C up to 7 h in a convective prototype (Section 2.2 of Materials and methods).

Fig. 2. Vitamin C retention (%) in dried strawberry samples under analysis (mean of three replicates ± SD in bars). Samples with the same letter (a-h) within the same drying temperature showed no statistically significant differences for their mean values at the 95.0% confidence level.
Fig. 3. Evolution with time of the 2-FM-AA content of strawberry samples dried under different experimental conditions: (a) 2-FM-Lys + 2-FM-Arg, (b) 2-FM-GABA.
Supplemental material

Fig. S1. Kinetic of vitamin C degradation in strawberry samples dried under different experimental conditions.

Fig. S2. RP-HPLC-UV profile of the acid hydrolyzate of strawberry sample dehydrated at 60 °C for 7 h and 4 m/s. Peak 1, 2-FM-GABA and peak 2, 2-FM-Lys + 2-FM-Arg.