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Impact of power ultrasound on chemical and physico-chemical quality indicators of strawberries dried by convection

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ABSTRACT

A study on the quality parameters of strawberries dehydrated by convection assisted by power ultrasound (US) at 40-70 °C and 30 and 60 W has been carried out for the first time. In general, the quality of US-treated samples was higher than that of commercial samples. Even under the most severe conditions used (US at 70 °C and 60 W), high values of vitamin C retention (>65%) and scarce advance of Maillard reaction (2-furoylmethyl derivatives of Lys and Arg < 90 mg/100 g protein) were observed. Rehydration ratio was not affected by the power applied and the obtained values were similar to those of convective treated samples. According to the results here presented, US is a suitable example of an emerging and environmentally friendly technology that accelerates the convective drying, allowing the obtainment of dried strawberries with premium quality.

Keywords: strawberry; ultrasound; convective dehydration; quality parameters; vitamin C; Maillard reaction

1. Introduction

A great awareness of healthy eating habits can be noticed among consumers and public and private institutions. In this sense, the interest in fruits and vegetables has increased during the last decades because of their considerable content in health promoting compounds. Among fruits, strawberry (*Fragaria x ananassa*) stands out not only by its nutritive value and palatability but also as a relevant source of bioactive compounds; vitamin C being one of the most important. Specific studies on the health benefits of vitamin C include its role in prevention of inflammation, oxidative stress, cardiovascular disease, cancer, type 2 diabetes, obesity and neurodegeneration (Du, Li, Ma, & Liang, 2009; Giampieri et al., 2012).

Fresh fruits and, particularly, strawberries are highly perishable, and processing is an alternative to extend their shelf-life. Among the available processes, dehydration and, mainly convective drying, is a common procedure to obtain products with reduced moisture content and easy to store and transport. Other advantages are linked to the diversification of dried products than can be offered to consumers, since they can be directly intake or used as ingredients in the elaboration of other foodstuffs. Thus, dehydrated fruits have a wide number of applications in breakfast cereals, bakery, desserts and confectionary products.

However, during processing and storage of dehydrated fruits, numerous physical and chemical changes can negatively affect their nutritional and sensorial quality (Derossi, De Pilli, & Fiore, 2010). One of the most important physical modifications is the shrinkage due to cellular structure stress brought about by high drying temperatures and long drying times, which can affect their rehydration properties (Frías, Clemente, & Mulet, 2010a; García-Pérez, Ozuna, Ortuño, Cárcel, & Mulet, 2011).

Regarding chemical reactions, vitamin C degradation is perhaps the most important change that might take place during fruit drying. In the case of strawberries, several works

have been focused on the loss of vitamin C during drying, and different retention values, between 98 and 16%, have been reported depending on the type and severity of the treatment (Böhm, Kühnert, & Scholze, 2006; Wojdylo, Figiel, & Oszmianski, 2009). Other reactions associated with the loss of quality in dried vegetables and fruits involve essential amino acids (Keutgen & Pawelzik, 2008); Maillard reaction being one of the most relevant. This reaction takes place between the free amino groups of amino acids, peptides and proteins, and reducing carbohydrates and it is favored at low water activities and high temperature conditions (Corzo-Martínez, Corzo, Villamiel, & del Castillo, 2012). 2-Furoylmethyl amino acids (2-FM-AA), obtained by acid hydrolysis of Amadori compounds formed during the initial steps of this reaction, are recognized as sensitive indicators for the early detection of changes in the quality of dehydrated commercial fruits (Sanz, del Castillo, Corzo, & Olano, 2001).

During recent years, emergent technologies have been proposed to reduce the limitations related to conventional drying techniques. As a non-thermal strategy in drying of fruits and vegetables, the application of high power ultrasound (US) represents a promising alternative. During drying, US produces in solid media alternative compressions and expansions cycles, namely "sponge effect", and the creation of internal microchannels that facilitate the water removal (Cárcel, García-Pérez, Benedito, & Mulet, 2012). Moreover, US generate microstirring at the solid-fluid interfaces that makes easier the mass transfer. In general, it has been reported that the application of US during drying of fruits and vegetables affects the kinetic of dehydration, decreasing significantly the processing time (Ortuño, Pérez-Munuera, Puig, Riera, & García-Pérez, 2010; Ozuna, Cárcel, García-Pérez, & Mulet, 2011; Puig, Pérez-Munuera, Cárcel, Hernando, & García-Pérez, 2012). In addition, Soria, Corzo, Martínez, Montilla, Riera, Gamboa-Santos & Villamiel (2010) reported that carrots dried in a US system by direct contact presented, in general, similar quality (total

polyphenols, rehydration ratio, protein profile) to freeze-dried samples and the advance of the Maillard reaction was much slower as compared to commercial dried carrots. These US treated samples also showed significantly lower losses of vitamins than carrots dried in a prototype of convective drying under different conditions (Frías, Peñas, Ullate, & Vidal-Valverde, 2010b). Very recently, our research group has studied the kinetic of humidity loss in strawberry samples dried in a convective system assisted by US (40-70 °C; 0-60 W) and, a significant increase in the effective diffusivity and the mass transfer coefficient was found (Gamboa-Santos, Montilla, Cárcel, Villamiel, & García-Pérez, 2014b). In spite of these works, no previous data have been reported on the overall quality of strawberry samples dried in a convective system assisted by US. Thus, the aims of this work were: i) to investigate the effect on vitamin C retention, 2-FM-AA formation and rehydration properties of US application (0-60 W) in the convective drying of strawberries and ii) to evaluate the microbiological quality and the evolution of chemical parameters after storage of dried strawberry samples.

2. Materials and methods

2.1. Ultrasound assisted drying treatments

Fresh strawberries (*Fragaria x ananassa* Duch.) were purchased from a local market in Valencia (Spain) and stored at 4 °C for up to 3 days until processing. Samples were washed in tap water to remove external impurities and cut into 2.5 ± 0.5 cm thickness slabs. Drying of strawberries was carried out in a US assisted convective drier prototype previously described by García-Pérez, Rosselló, Cárcel, de la Fuente, & Mulet (2006). The processing conditions were: temperatures of 40, 50, 60 and 70 °C, electric power applied to the air-borne

US transducer: 0, 30 and 60 W and air speed: 2 m s^{-1}. Dried strawberry samples were coded as shown in Table 1.

Slabs were placed in a metallic frame to allow free air flow around each piece of strawberry. Samples (initial mass: 73.5 ± 3.5 g; initial moisture content: 9.55 ± 0.27 kg H_2O kg^{-1} dry matter (DM)) were dried until a constant weight of 8.1 ± 1.0 g (final moisture content: 0.16 ± 0.10 kg H_2O kg^{-1} DM) for drying times ranging 2.4 to 5.5 h. Weight of strawberries was recorded at 3 min intervals during the whole drying process. Each drying experiment was carried out in triplicate.

Strawberry samples dried at 70 °C with and without US application (samples US-70-60 and nonUS-70, respectively), were packed in polypropylene individual bags under vacuum, and then stored in the dark for a period of 6 months at 25 ± 1 °C, to study the evolution of the microbiological quality and the vitamin C retention, and for 1 month at 45 ± 1 °C to determine the advance of the Maillard reaction.

2.2. Sample characterization

Dry matter (DM) content was gravimetrically determined (AOAC, 1990a). Kjeldahl method was performed to determine total nitrogen (TN), using 6.25 as conversion factor (TN x 6.25) to calculate the protein content (AOAC, 1990b). All determinations were carried out, at least, in triplicate.

2.3. Microbiological analysis

Strawberries dried at 40 °C (nonUS-40; US-40-60) and 70 °C (nonUS-70; US-70-60) were analyzed after processing and after storage at ambient temperature (6 months) for their total aerobic, enterobacteria, molds and yeasts and sporulated aerobic and anaerobic

135 microorganisms. Samples (1.5 g) were placed with 27 mL of peptone water (sterile peptone,
136 2.55%) in a sterile stomacher bag and then were homogenized into the stomacher for 1 min
137 (230 rpm), filtered and diluted with peptone water for the microbial count. Serial dilutions
138 were performed in triplicate. The total aerobic bacteria and enterobacteria counts were
139 determined by plating appropriately diluted samples onto plate count agar and violet red bile
140 dextrose agar, respectively. The samples were incubated at 30 ± 1 °C for 72 h for total
141 aerobic bacteria and for 24 h for enterobacteria. Yeasts and molds were plated on sulphite
142 cycloserine agar and incubated at 25 ± 1 °C for 5 days. For aerobic and anaerobic sporulated
143 counts, brain heart infusion agar was used; incubation was carried out at 37 ± 1 °C for 48 h.
144 All culture media were of Difco (Difco Co., Detroit, MI, USA). Microbial counts were
145 reported in all cases as logarithm of colony forming units per gram (log CFU g^{-1}).
146 Microbiological quality was evaluated according to the European legislation for vegetables
147 and fruits (EC 2073/2005).
148

149 *2.4. Determination of vitamin C*

150 Strawberry extracts were prepared in triplicate by adding 12.5 mL of 0.4% oxalic acid
151 to 0.25 g of strawberry samples and homogenizing for 1 min at 13,500 rpm using an Ultra-
152 Turrax T-35 homogenizer (IKA Labortechnik, Janke & Kunkel, Saufen, Germany) (Gamboa-
153 Santos et al., 2013). After addition of 2.5 mL of a 5 mg mL^{-1} solution of D,L-dithiothreitol, to
154 reduce the dehydroascorbic acid to ascorbic acid, strawberry extracts were kept at room
155 temperature in the darkness for 30 min. Slurries were made up to 25 mL with Milli-Q water
156 prior to centrifugation at 3,200 *g* for 5 min.

157 Total vitamin C content of strawberries was determined by Reversed Phase-High
158 Performance Liquid Chromatography with Diode Array Detection (RP-HPLC-DAD) on an

159 Agilent Technologies 1220 Infinity LC System – 1260 DAD (Boeblingen, Germany).
160 Vitamin C separation was done with an ACE 5 C_{18} column (ACE®, UK) (250 mm length x
161 4.6 mm internal diameter, 5 μm) at 25 °C, using 5 mM KH_2PO_4 buffer (pH 3.0) as the mobile
162 phase. The elution program was performed under isocratic conditions at a flow rate of 1 mL
163 min^{-1} for 10 min. Automatic injection volume was 20 μL. Data acquisition and processing
164 was done using the Agilent ChemStation software (Agilent Technologies, Germany).
165 Vitamin C content was quantified by the external standard method, using a commercial
166 standard of ascorbic acid (Sigma) (0.3-50 mg L^{-1}). Results were expressed as mg of total
167 vitamin C 100 g^{-1} DM and the percentage of retention was calculated taking into account the
168 initial content of vitamin C in raw strawberries.
169
170 *2.5. Analysis of 2-furoylmethyl amino acids*
171 Samples (0.25 g of dried strawberries) were hydrolyzed under inert conditions
172 (nitrogen) with 4 mL of 8 M HCl at 110 °C for 23 h using screw-capped Pyrex vials with
173 polytetrafluoroethylene-faced septa. After filtering (paper filter Whatman no. 40), 0.5 mL of
174 the resulting hydrolyzates were passed through a Sep-Pack C_{18} cartridge (Millipore, MA)
175 previously activated with 5 mL of methanol and 10 mL of Milli-Q water. The filtrate was
176 then eluted with 3 mL of 3 M HCl.
177 2-FM-AA were determined by ion-pair RP-HPLC according to Soria et al. (2010),
178 using a C_8 column (250 mm length x 4.6 mm internal diameter, Alltech, Lexington, KY)
179 thermostated at 37 °C. Phase A (4 mL L^{-1} acetic acid) and phase B (3 g L^{-1} KCl in phase A
180 solution) were used to make a binary gradient: 0-12.0 min, 100% A; 20.0–22.5 min, 50% A;
181 24.5-30.0 min, 100% A. The flow rate was 1.2 mL min^{-1}, the injection volume was 50 μL and
182 detection was done at 280 nm (LCD Analytical SM 4000 detector).

183 Quantitation of samples was performed by the external standard method, using a
184 commercial standard of furosine (Neosystem Laboratoire, Strasbourg, France). Values were
185 expressed as mg 100 g^{-1} protein and analyses were done in triplicate.
186

187 *2.6. Rehydration ability*

188 Dried strawberry samples were rehydrated by immersion in distilled water (solid-to-
189 liquid ratio 1:50) at 25 °C for 2 h, as described by Soria et al. (2010). Before weighting the
190 samples, strawberry slabs were placed onto paper towels to remove the superficial water.
191 Each rehydration experiment was performed in triplicate and rehydration ratio was calculated
192 as follows:

193 $$\text{Rehydration ratio} = m_r/m_d,$$

194 where m_r and m_d represent the weight of the rehydrated and dehydrated strawberry,
195 respectively.
196 Rehydration water was placed in a pre-weighed vial and dried in a conventional oven
197 for 24 h at 102 °C. The residue thus obtained was weighed to determine the percentage of
198 leached solids (% DM) with respect to the initial weight of strawberry.
199

200 *2.7 Statistical Analysis*

201 Data were subjected to one-way analysis of variance (ANOVA) (Fischer LSD Test, $p <$
202 0.05) by applying the Statgraphics 5.1 statistical package (Statistical Graphics Corp.,
203 Rockville, MD).

204

205 **3. Results and discussion**

206 *3.1. Microbiological quality*

207 The microorganism determination in just processed strawberries under study (nonUS-
208 40, US-40-60, nonUS-70 and US-70-60) (Table 2) indicated that total aerobic bacteria,
209 enterobacteria, yeast and molds, aerobic and anaerobic sporulated counts were, in all cases,
210 including nonUS-70 and US-70-60 samples stored for 6 months, lower than 3 log CFU g^{-1}.
211 According to the microbiological criteria recommended for vegetables, fruits and derivatives,
212 the maximum limits are 2-3 log CFU g^{-1} for molds and yeasts and 5 log CFU g^{-1} for aerobic
213 mesophylls (EC 2073/2005). Therefore, processing and storage conditions were adequate to
214 guaranty the microbial stability of samples during, at least, 6 months.

215

216 *3.2. Retention of vitamin C*

217 As aforementioned, the quality of dried strawberry samples was evaluated from their
218 vitamin C content. In agreement with other works, vitamin C is considered a compound very
219 sensitive to processing conditions, and a non-subjective and relatively easy-to-measure
220 criterion of food quality (Ryley, 1989). It has also been reported that if vitamin C is
221 conveniently retained, other nutrients can be also well preserved (Shitanda & Wanjala, 2006).
222 The vitamin C amount experimentally determined in raw strawberry samples was in the
223 range 271.9-494.0 mg 100 g^{-1} DM. This wide variability could be associated, among others,
224 with the slight differences in the degree of ripeness of the samples analysed. Values here
225 reported are in agreement with those previously determined by Wojdylo et al. (2009) for fresh
226 strawberries (in the range 340.2 – 680.2 mg 100 g^{-1} DM).

Fig. 1 illustrates the vitamin C retention (taking into account the initial content in the raw fruit) determined in strawberries dried at temperatures between 40 and 70 ºC, with (30 and 60 W) and without US application (0 W). As can be observed, high levels of retention (65-84%) were found in all processed strawberry samples. Considering the effect of temperature for a fixed US power (Fig. 1A), the highest preservation of vitamin C was obtained after treatments carried out at 40 and 50 ºC, being the vitamin C degradation higher when the temperature increased. Irrespective of the US power applied (0, 30 or 60 W), no significant differences ($p < 0.05$) were found for strawberries processed at 60 and at 70 ºC, as the effect of a higher temperature was probably counterbalanced by a decrease in processing time (Table 1). Values of 70-81% and 40-74% have been described in a previous work where strawberry samples were processed in a convective drier at 60 ºC (4 m s^{-1}) and at 70 ºC (2 m s^{-1}), respectively, for 3-7 h (Gamboa-Santos, Megías-Pérez, Soria, Olano, Montilla, & Villamiel, 2014a). Wojdylo et al. (2009) found retention values of ascorbic acid of 30% for strawberry samples (var. *Kent* and *Elsanta*) dehydrated at 70 ºC and 1 m s^{-1} for 9 h. Böhm et al. (2006) reported retentions of 31-42% for ascorbic acid in three strawberry varieties dehydrated at 60 ºC and 5 m s^{-1} for 220 min.

As regard as the effect of US power for a fixed temperature (Fig. 1B), a significant decrease of vitamin C retention was found when US was applied at temperatures higher than 40 ºC. Despite the treatments at 50 - 70 ºC assisted by US were shorter as compared to those without US application (Table 1), more degradation of vitamin C was observed in the former, most likely due to a combined effect of both temperature and US. According to Dennison & Kirk (1978), US could facilitate the air penetration in the sample and, as it is known, oxygen is one of the most detrimental factors in the stability of ascorbic acid. Nevertheless, it is noteworthy that, even under the most severe conditions (70 ºC and 60 W), the retention values of vitamin C were high (65%) and within the range previously reported in the

252 literature for convective dried strawberry samples (Böhm et al., 2006; Gamboa-Santos et al.,
253 2014a; Wojdylo et al., 2009). Moreover, the final content of vitamin C in these strawberry
254 samples (247.6 mg 100 g^{-1} DM) after storage was higher than convective dried samples
255 (lower than 64.7 mg/100 g DM) and only a freeze-dried commercial sample had upper
256 vitamin C content (365.0 mg/100 g DM) (Megías-Pérez, Gamboa-Santos, Soria, Villamiel, &
257 Montilla, 2014).

258 To date, no previous studies have been performed on the impact of US application on
259 vitamin C degradation during convective drying of fruits. Frías et al. (2010) reported
260 retention values of vitamin C ranging from 82-92% in sliced carrots (4 x 24 mm) subjected to
261 dehydration in a US system by contact (100 W) at temperatures of 20-60 °C and drying times
262 of 75-120 min. The higher retention values reported in that paper can be ascribed, not only to
263 the different products being dried, but also to the different drying systems used, since
264 processing conditions (temperature and time) in the US system by contact were milder than
265 those of the air-borne US system here used.

266 Regarding the vitamin C content evolution during sample storage at 25 °C for 6
267 months, strawberry samples dried at 70 °C without (nonUS-70) and with (US-70-60) US
268 application reached a loss of 57.1 ± 0.9% and 57.0 ± 2.6%, respectively, as compared to just
269 dried samples, being the final vitamin C content of 78.6 and 85.5 mg 100 g^{-1} DM. These
270 values of vitamin C degradation during the storage are close to those scarcely reported in the
271 literature. Del Caro, Piga, Pinna, Fenu & Agabbio (2004) investigated the ascorbic acid
272 losses of two varieties of prunes subjected to drying at 60-85 °C and stored at 20 °C. They
273 found ascorbic acid retentions ranging from 50 to 69% after 4-8 months of storage. In dried
274 vegetables, Peñas, Sidro, Ullate, Vidal-Valverde & Frias (2012) reported highly variable
275 (from 28 to 93%) reductions in the vitamin C content of commercial vacuum packaged and
276 laboratory freeze-dried garlic, onion, potato and carrot samples after 12 months of storage at

277 room temperature. Kim, Lee, Park, Lee & Hwang (2006) determined a loss of 75% of
278 vitamin C in dried pepper (70 °C for 6 h) after 6 months of storage at 20 °C. Similarly, losses
279 of vitamin C close to 60% were also observed by Megías-Pérez, Gamboa-Santos, Soria,
280 Villamiel & Montilla (2012) after the storage (6 months at room temperature) of crunchy
281 pepper obtained by texturization using an expanded microperforation technique and packed
282 in plastic bags with modified atmosphere.
283

284 *3.3. Assessment of initial steps of Maillard reaction*

285 Fig. 1S depicts the RP-HPLC-UV chromatographic profile of 2-FM-AA obtained after
286 acid hydrolysis of strawberries dried at 70 °C and 60 W (US-70-60). Identification of 2-FM-
287 derivatives of γ-aminobutiric acid (2-FM-GABA, peak 1) and lysine plus arginine (2-FM-Lys
288 + 2-FM-Arg, peak 2) was tentatively carried out by comparing the experimental retention
289 times with data obtained for standards synthesized in our laboratory and by coinjection with
290 these standards (Sanz et al., 2001; Soria et al., 2010). The strawberry composition in free
291 amino acids was also taken into account (Blanch, Sanchez-Ballesta, Escribano, & Merodio,
292 2012).

293 Fig. 2 shows the effect of temperature at a fixed power on the content of 2-FM-AA
294 found in strawberry samples dried under the different processing conditions here assayed. As
295 observed, 2-FM-Lys + 2-FM-Arg (Fig. 2A) were formed in higher amount (up to 90 mg 100
296 g^{-1} protein) as compared to 2-FM-GABA (Fig. 2B) (up to 60 mg 100 g^{-1} protein), due to the
297 different reactivity of the corresponding amino acids (Wellner, Huettl, & Henle, 2011).
298 Considering the effect of temperature for a fixed power level, above 50 °C 2-FM-AA
299 contents significantly increased with the temperature, being this effect particularly evident at
300 70 °C and for 2-FM-Lys+2-FM-Arg. Gamboa-Santos et al. (2014a) found 2-FM-Lys + 2-FM-

Arg and 2-FM-GABA amounts in the ranges 35-265 mg 100 g^{-1} protein and 30-198 mg 100 g^{-1} protein, respectively, in strawberry samples processed in a convective drier for 3 h at 40-70 °C and at air flow rates of 2-8 m s^{-1}, whereas no formation of these compounds was detected during the first hour of treatment. Moreover, in commercial dehydrated strawberry samples, Megías-Pérez et al. (2014) quantified 2-FM-Lys + 2-FM-Arg contents in the range 46-475 mg 100 g^{-1} protein for lyophilized samples and values up to 982 mg 100 g^{-1} protein for convectively dried ones. These indicators have also been previously detected in commercial samples of dried raisins, apricots, dates and figs and the concentrations were between 7.7 and 62.5 mg 100 g^{-1} product for 2-FM-Lys + 2-FM-Arg and between 3.6 and 75.8 mg 100 g^{-1} product for 2-FM-GABA. These amounts were higher than those found in the strawberries dried without US here analyzed, with contents between 1.2 and 6.7 mg 100 g^{-1} product and 1.2 and 4.0 mg 100 g^{-1} product, respectively for both indicators.

Comparing US-treated samples with those without US (Fig. 3), lower concentrations of 2-FM-Lys and 2-FM-Arg were found in US-treated samples processed at 60-70 ºC, whereas at lower temperatures, US application was shown to only affect 2-FM-Lys and 2-FM-Arg (A) contents when US power was high (60 W). In the case of 2-FM-GABA (B), the levels determined at different temperatures were similar irrespective of the US power applied. The results above mentioned seem to evidence the higher impact of drying temperature over US power on these quality markers.

Moreover, during the storage of samples at 45 °C for 1 month, strawberry samples treated at 70 °C without US (nonUS-70) presented amounts of 2-FM-Lys + 2-FM-Arg of 765 ± 12 and of 1158 ± 27 mg 100 g^{-1} protein after 7 and 30 days, respectively. Similarly, levels of 706 ± 60 and 1112 ± 89 mg 100 g^{-1} protein were determined in strawberries dried with US (US-70-60) after 7 and 30 days of storage, respectively.

To the best of our knowledge, no previous work has been reported on the Maillard reaction assessment in dehydrated fruits processed by convection assisted by US. Soria et al. (2010) studied the effect of temperature in 2-FM-AA formation in carrots dehydrated with US application (100 W) in a system by direct contact. These authors did not detect 2-FM-AA at drying temperatures below 40 °C and, at 60 °C, 2-FM-Lys + 2-FM-Arg levels up to 39 mg 100 g^{-1} protein were found. Comparing these results with the obtained in the present work, the differences could be ascribed, among other factors, to the milder conditions (temperature and time) used in the US system by direct contact, although also can have influence the higher content of reducing carbohydrates of strawberries.

3.4. Rehydration properties

Tables 3 and 1S list the rehydration ratio of strawberry samples dried at different temperatures (40-70 ºC) with (30 and 60 W) and without (0 W) US application. As it can be seen, rehydration ratios ranged from 4.0 to 5.1. These values were lower than that reported for a laboratory freeze-dried (FD) sample (6.5) and similar to those of commercial FD strawberry samples (5.2 on average) (Megías-Pérez et al., 2014). In general, rehydration ratio values obtained were in agreement with data previously reported for dried fruits and vegetables (El-Beltagy, Gamea, & Essa, 2007). For a fixed temperature (Table 3), no significant differences ($p < 0.05$) related with the US power applied were found for rehydration ratios of strawberries.

Considering the conventionally dried samples (without US) (Table 1S), rehydration ratio decreased with the temperature, but differences were only significant ($p < 0.05$) between the highest (70 ºC) and the lowest (40ºC) drying temperature. This is consistent with the fact that fruit structure dried at high temperatures might be partially disrupted as compared with

349 the fresh product (McMinn & Magee), causing an irreversible shrinkage and making the
350 recovery of the initial moisture content of the sample not possible. This effect is more evident
351 in heat-sensitive materials, in which drying can induce crust formation on the surfaces, so that
352 water penetration into the samples is reduced. Moreover, the open and porous structure of FD
353 strawberry samples, that facilitates the water absorption, is probably responsible for its high
354 rehydration ratio (Shih, Pan, McHugh, & Wood, 2008).

355 For both US power tested (30 or 60 W) (Table 1S), no clear trend was found regarding
356 the influence of temperature on rehydration ratio, although in general the lowest values were
357 also found for samples treated at 70 ºC. In carrots, Soria et al. (2010) found higher values of
358 rehydration ratio in samples dried by US in a system by direct contact as compared to freeze-
359 dried samples, when carrots were blanched prior to US treatment. In the case of US treated
360 strawberries here analysed, an improved rehydration ratio could have been expected probably
361 due to the formation of microchannels, or other structural damages, in the fruit tissue.
362 However, the mechanisms of US affecting water removal are multiple including, among
363 others, cell disruption. The convective boundary layer can be affected by the pressure
364 variations and microstirring induced by US (Mulet, Cárcel, Sanjuán, & Bon, 2003). Thus,
365 García-Pérez, Ortuño, Puig, Cárcel & Pérez-Munuera (2012) identified an intense spread of
366 waxy compounds on the surface of orange peel flavedo, which was coupled to a high water
367 evaporation rate; while the inner water removal was mainly improved by the cyclic
368 compressions and expansions produced by US (Gallego-Juárez, 1998), which in certain way
369 could also affect internal structure, such as was observed in orange peel (García-Pérez et al.,
370 2012) and eggplant (Puig et al., 2012). According to Schössler, Thomas & Knorr (2012), the
371 cell disruption induced by US is mainly produced in the outer layer and the damage
372 originated in deeper layers is mainly attributed to structural modifications associated with the
373 water removal. However, the US effects could be dependent on the effective ultrasonic power

applied and, therefore, comparison of results obtained with different US systems results complicated. Moreover, the absorption of US as heat could also contribute to the evaporation of water from the inner tissue and also could induce structural changes.

With respect to the corresponding leaching losses during rehydration of dried strawberry samples, they were found to be in the range 61.8-77.6%. Similar leaching losses were observed by Megías-Pérez et al. (2014) in freeze dried (46.3-72.4%) and convective dried berry fruits (59.3-90.9%). These data highlight the convenience of consuming dried strawberries not rehydrated or together with the foodstuffs in which strawberries are rehydrated.

4. Conclusions

According to the quality parameters determined in the present study, the application of US during convective drying is an adequate procedure to obtain dried strawberry samples with high quality and appropriate microbiological stability. Losses of lysine and arginine due to their involvement in the Maillard reaction were similar to those observed in conventionally dried (no US-treated) strawberries. Moreover, the amounts of 2-FM-AA were, in all cases, lower than those of commercial dried strawberries and other fruit samples. Values of vitamin C retention were very high (≥ 65%), even under the most severe conditions used (US at 70 °C and 60 W). A combined effect of US and heat was observed, since the lowest retention of vitamin C was found in US-assisted dried samples at high temperature. Furthermore, the obtained values of vitamin C retention and rehydration properties in US treated strawberries were within the ranges reported in the literature for convective dried fruits and vegetables. Finally, in samples treated at 70 °C with and without US, during the storage at ambient temperature, no changes in the microbiological counts were detected with respect to the

initial processed samples, indicating the stability of US-treated samples during at least 6 months. Moreover, these samples showed similar evolution in the losses of vitamin C (aprox. 50%) during the storage period. According to the data here shown, the best processing conditions (temperature and electric power applied to the air-borne US transducer) could be 50 ºC and 30 or 60 W of US power. This is the first study on the evaluation of quality indicators of fruits, particularly strawberries, dehydrated by US-assisted drying. The results of this work point out that US is a suitable example of an emerging and environmentally friendly technology that accelerates the convective drying, allowing the obtainment of dried strawberries with premium quality which satisfy the demands of the present consumers.

Abbreviations used

2-FM-AA: 2-furoylmethyl amino acids

US: high power ultrasound

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537
538

FIGURE CAPTIONS

Figure 1. Effect of temperature (A) and US power (B) on the retention of vitamin C in convectively dried strawberries by US assistance (values referred to the initial content in the raw fruit). *Samples with the same superscript letter ($^{a-b}$) within the same US power (A) or temperature (B) showed no statistically significant differences for their mean values at the 95% confidence level.

Figure 2. Effect of temperature of drying on the 2-FM-Lys + 2-FM-Arg (A) and 2-FM-GABA (B) contents of convectively dried strawberries by US assistance. *Samples with the same superscript letter ($^{a-d}$) within the same US power showed no statistically significant differences for their mean values at the 95% confidence level.

Figure 3. Effect of power ultrasound application on the 2-FM-Lys + 2-FM-Arg (A) and 2-FM-GABA (B) contents of convectively dried strawberries by US assistance. *Samples with the same superscript letter ($^{a-d}$) within the same temperature showed no statistically significant differences for their mean values at the 95% confidence level.

Table 1. Codification of processing conditions applied in the ultrasound assisted drying of strawberries. In brackets, processing time (h) for each drying experiment.

Power	**Temperature (°C)**			
(W)	**40**	**50**	**60**	**70**
0	nonUS-40 (5.3)	nonUS-50 (4.7)	nonUS-60 (4.4)	nonUS-70 (3.3)
30	US-40-30 (5.5)	US-50-30 (3.9)	US-60-30 (3.5)	US-70-30 (2.8)
60	US-40-60 (4.8)	US-50-60 (3.3)	US-60-60 (2.8)	US-70-60 (2.4)

Table 2. Maximum values of microorganism counts (CFU/g) in dried strawberry samples: nonUS-40 and US-40-60 after processing and nonUS-70 and US-70-60 after processing and 6 months of storage at 25°C.

Microorganism evaluated	Counts (CFU/g)					
	nonUS-40 (0 months)	US-40-60 (0 months)	nonUS-70		US-70-60	
			(0 months)	(6 months storage)	(0 months)	(6 months storage)
Total aerobic bacteria	4.0×10^2	2.4×10^2	5.0×10^1	2.0×10^1	1.0×10^2	2×10^1
Enterobacteria	$< 10^1$	$< 10^1$	2.0×10^1	$< 10^1$	$< 10^1$	$< 10^1$
Aerobic sporulated	4.0×10^1	3.2×10^2	$< 10^1$	6.0×10^1	10^1	$< 10^1$
Anaerobic sporulated	2.0×10^2	$<10^2$	10^2	$<10^2$	$<10^2$	$< 10^2$
Yeast and molds	$<10^2$	$< 10^3$	$<10^2$	$< 10^3$	$<10^2$	$< 10^3$

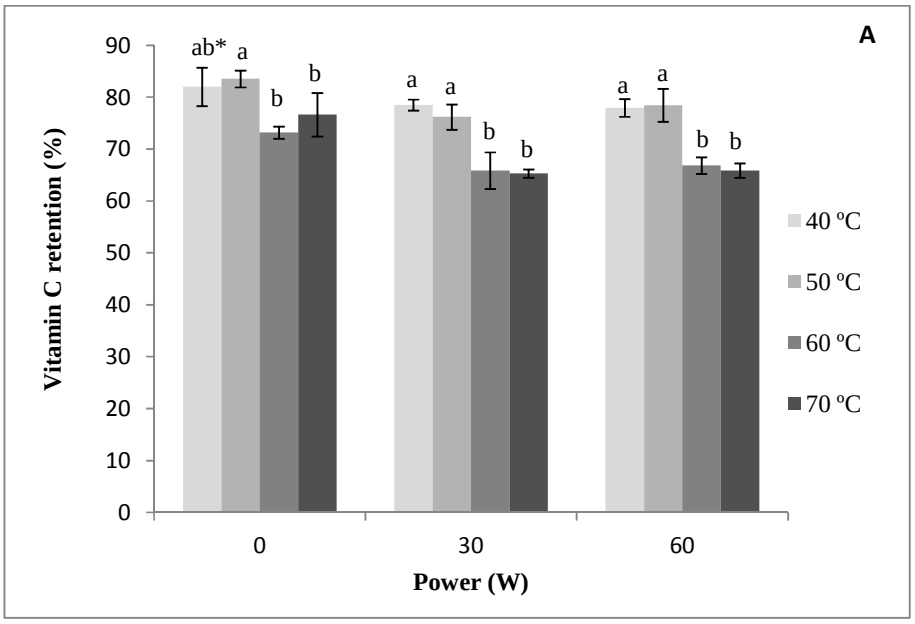
Table 3. Rehydration ratio of convective dried strawberries (mean value ± SD).

Temperature (°C)	Rehydration ratio		
	0 W	**30 W**	**60 W**
40	$5.1 \pm 0.4^{a*}$	4.7 ± 0.4^{a}	5.0 ± 0.5^{a}
50	4.8 ± 0.3^{a}	4.7 ± 0.3^{a}	4.0 ± 0.3^{b}
60	4.7 ± 0.5^{a}	5.1 ± 0.2^{a}	5.0 ± 0.3^{a}
70	4.4 ± 0.1^{a}	4.4 ± 0.4^{a}	4.2 ± 0.2^{a}

*Samples with the same superscript letter ($^{a-b}$) within the same row showed no statistically significant differences for their mean values at the 95% confidence level.

Figure(s)

Figure 1. Gamboa-Santos et al.



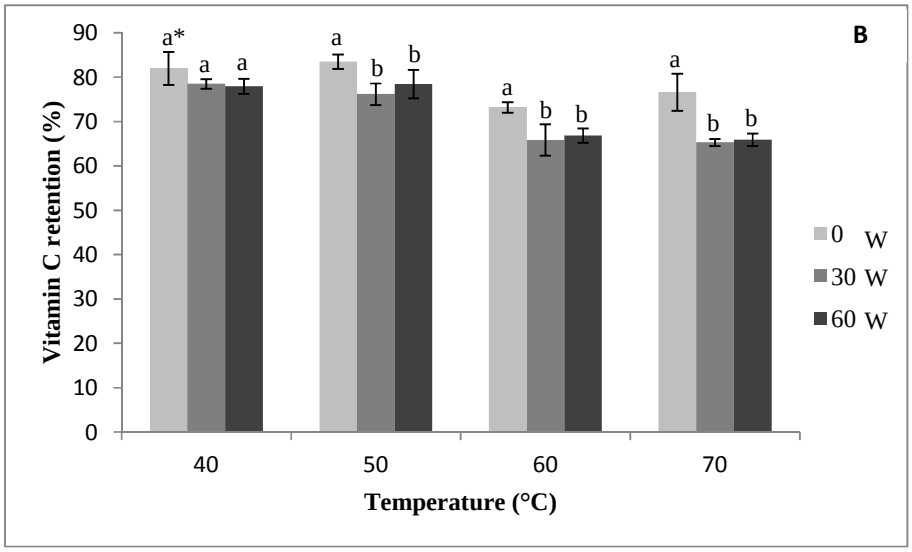


Figure 2. Gamboa-Santos et al.

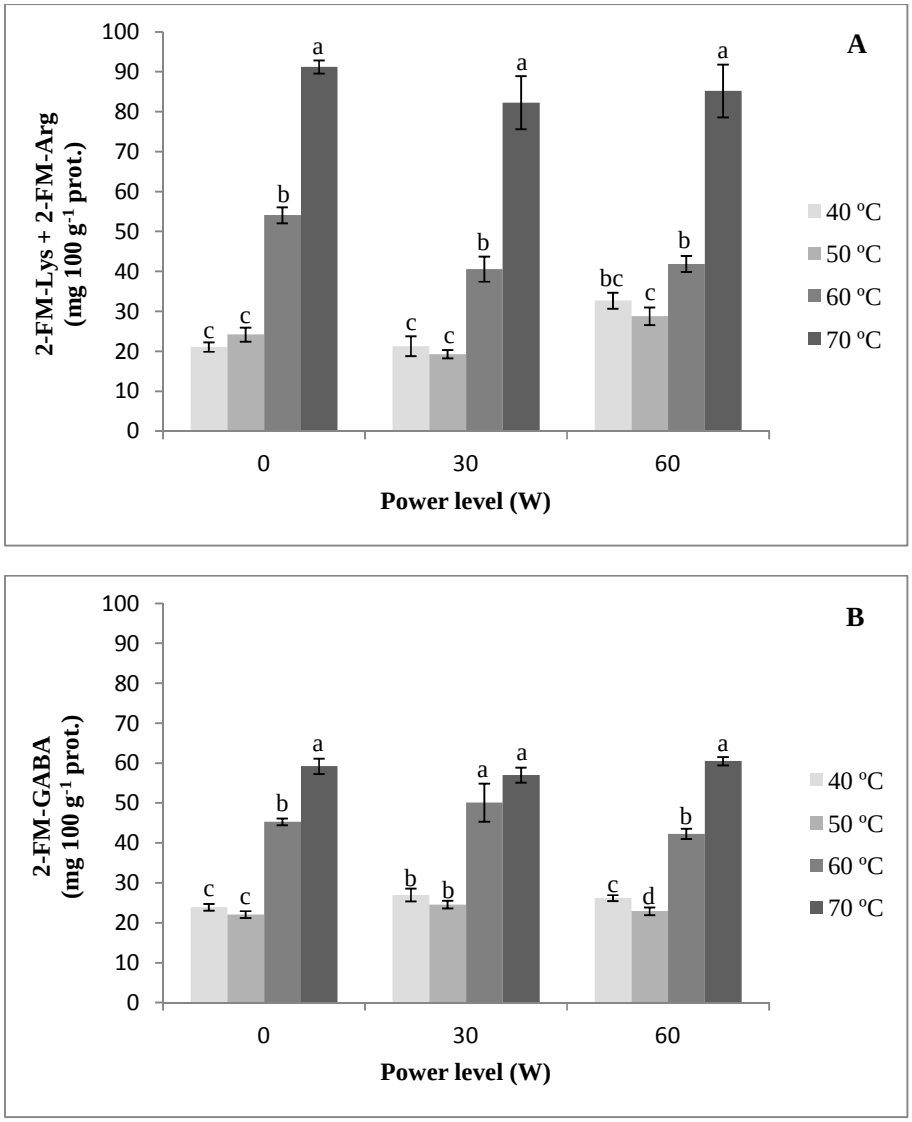


Figure 3. Gamboa-Santos et al.