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Influence of osmotic dehydration pre-treatment on oven drying and freeze drying performance

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Abstract

Drying is largely used in food industry, since it allows prolonging the product shelf life by inhibiting microorganisms' growth and enzyme activity. Traditional drying techniques, such as air drying and freeze drying, suffer from several drawbacks, mainly long processing time, low rehydration capacity and change in food properties. Some pre-treatments, such as osmotic dehydration, can be applied prior to conventional techniques in order to produce an intermediate moisture product and, therefore, to improve the drying process. In this work, the influence of osmotic dehydration on oven drying and freeze drying performance was evaluated. Firstly, the effects of the main osmotic dehydration parameters were investigated in order to find the best conditions for water desorption. Secondly, experiments with oven drying, freeze drying and their combination with osmotic pre-treatment were carried out. Results of each technique in terms of final moisture content, water activity, rehydration ability, textural properties and microstructure were compared and discussed. It has been observed that the application of the pre-treatment allows reducing considerably the processing time and better retaining the food properties.

Keywords: Food drying, Osmotic dehydration, Oven drying, Freeze drying, Rehydration.

1. Introduction

Food market increasingly requires the development of techniques able to extend foodstuffs shelf-life, since consumers demand fresh-quality products without the use of preservatives (Maskan, 2001).

Fruits and vegetables are highly perishable foods, since they easily undergo degradation reactions by bacteria proliferation, because of their elevated moisture content (Dev & Raghavan, 2012). For this reason, several industrial processes have been developed for their preservation. Among them drying is the most common method, since water removal inhibits microorganisms' growth and enzyme activity and decreases the weight of the product, simplifying also its transport and storage (de Bruijn et al., 2016). For these purposes, dried foods should have water content lower than 25 g/100 g and water activity lower than 0.6 (de Bruijn et al., 2016; Stevenson et al., 2015). Water activity (a_w) is a measure of the quantity of water that is available for chemical and biological reactions, so it represents an indication of food stability with respect to microbial growth (Oliveira, Brandão, & Silva, 2016). On the other hand, downstream the drying process, it should be possible to recover the properties of the fresh food rehydrating the dried. Rehydration ability depends on the degree of cellular and structural disruption; therefore, it is considered as a measure of the damage caused by drying to the food structure (Vega-Gálvez et al., 2015).

Different drying processes have been proposed in literature. The most popular and ancient dehydration technique is air drying, in which moisture is removed by evaporation (Ratti, 2001). However, several authors reported that this process can cause several adverse effects on food attributes such as case hardening, shrinkage, poor rehydration ability and the alteration of the sensory features (Maskan, 2000). Another common technique is

48 represented by freeze drying, which consists in the freezing of the product and then water
49 removal by sublimation. This technique allows to retain food quality and structure better
50 than other dehydration processes , but it suffers from some drawbacks, such as high energy
51 costs and very long processing times, which restricts its applicability to high-value products
52 (Karam, Petit, Zimmer, Baudelaire Djantou, & Scher, 2016).
53 In order to optimise moisture desorption, some pre-treatments have also been
54 proposed, with the aim to produce an intermediate moisture product. Among them,
55 osmotic dehydration has received much attention due to its low cost and complexity. This
56 process consists of the immersion of the foodstuff in a hypertonic solution: in this way
57 moisture diffuses from the food towards the solution thanks to the semi-permeability of the
58 cell membrane and, in the opposite way, the solute used as osmotic dehydrator flows from
59 the solution to the food, even if in minor extent (da Costa Ribeiro, Aguiar-Oliveira, &
60 Maldonado, 2016). Different authors (Rastogi & Raghavarao, 1997; Tsotsas & Mujumdar,
61 2014) reported that this method allows reducing water content up to 50 % weight. In order
62 to complete the drying, other methods, as those mentioned above, need then to be applied.
63 In literature many papers are focused on osmotic dehydration and its application
64 prior to microwave drying (Botha, Oliveira, & Ahrné, 2012; Corrêa, Dev, Gariepy, &
65 Raghavan, 2011; de Bruijn & Bórquez, 2014; Prothon et al., 2001), but limited studies have
66 been performed till date on osmotic dehydration + oven drying and osmotic dehydration +
67 freeze drying. In these studies, the authors focused their attention on water desorption, but
68 rarely on the effects of drying on water activity, rehydration capacity and food
69 microstructure in order to have a comprehensive overview of the process. De Costa Ribeiro
70 et al. (da Costa Ribeiro et al., 2016) observed that when osmotic dehydration was applied
71 prior to conventional oven drying, a reduction of 41.8 % of the drying time was possible to

achieve a pear final moisture content of 0.25 kg/kg dry solids; however, they did not report the samples' final water activity and rehydration capacity. Patil et al. (Patil, Kalse, & Jain, 2012) also observed that the application of the pre-treatment to convective drying allowed to reduce onion drying time by approximately 40 % but the effect on samples' water activity and microstructure was omitted. Ruiz-López at al. (Ruiz-López, Huerta-Mora, Vivar-Vera, Martínez-Sánchez, & Herman-Lara, 2010) pointed out that the osmotic dehydration pre-treatment led to a significant decrease in chayote moisture content, allowing to reduce air-drying time up to 65 % depending on the used dehydrator; however, also in this case, information about water activity, rehydration ability and structural properties were missing.

In the present work, osmotic dehydration was applied prior to oven drying and freeze drying in order to improve their performances. The model food chosen for the experimentation was strawberry, since it is one of the most consumed fruits, thanks to its enjoyable organoleptic characteristics and its healthy properties. First, an optimisation of the pre-treatment operating conditions was carried out in order to identify the best conditions for the highest water desorption. Several experiments were then performed using oven drying, osmotic dehydration + oven drying, freeze drying and osmotic dehydration + freeze drying. The results in terms of samples' final moisture content, water activity, rehydration ability and quality retention were compared and discussed.

2. Materials and methods

2.1 Materials

Fructose (purity ≥ 99 %), Maltodextrin (purity ≥ 99.5 %), Maltose (purity ≥ 95 %) and Sucrose (purity ≥ 99.5 %) were supplied by Sigma Aldrich (UK). All materials were used as received. Fresh strawberries (*Malling centenary*) were purchased by a local supermarket

and stored in a refrigerator at 5 °C. After washing in tap water and draining with blotting paper, strawberries were cut into cubes of 1 cm^3.

2.2 Osmotic dehydration

Osmotic dehydration experiments were carried out by immersion of 10 g of strawberry cubes in the osmotic solution, at fixed temperature, under stirring at 250 rpm. The fruit to solution ratio (F:OS) was fixed at 1:10. At the end of each experiment, samples were taken and blotted with paper.

2.3 Oven drying

Conventional drying tests were carried out introducing strawberry cubes in an oven (Fistreem International Co. Ltd, Leicestershire, UK) with no flow air, at room pressure and fixed temperature.

2.4 Freeze drying

Fresh cubic samples were frozen at -20 °C and then lyophilised using a bench top Freeze Dryer (SCANVAC Coolsafe™, model 110-4, Lynge, Denmark), condenser temperature-110 °C, pressure 10 Pa.

2.5 Moisture content analysis

Moisture content (MC) analyses were carried out using a moisture analyser (model MB 25, OHAUS, Nanikon, Switzerland). Two grams of sample were placed within the aluminium pans and located over the pan support of moisture meter. Halogen element inside the moisture meter provides uniform infrared heating. It heats the sample at a set

119 temperature of 120 °C until the sample weight becomes constant. Moisture percentage as a
120 function of weight change is recorded and displayed. Strawberry initial moisture content
121 was found to be equal to 86.4 g/100 g.
122
123 2.6 Water activity analysis
124 Water activity (a_w) of fresh and dried samples was measured using an AquaLab® dew
125 point water activity meter (model 4TE, Decagon Devices Inc., Pullman, WA, USA). The
126 temperature controlled sample chamber was set to 25 °C. The water activity of the fresh
127 samples was found to be equal to 0.988.
128
129 2.7 Soluble solids gain determination
130 Total solids content (SS) was determined by direct reading using an automatic
131 refractometer (Model J357, Rudolph Research Analytical, Hackettstown, NJ, USA). The solids
132 gain (SG %) was calculated using the following equation (Campos, Sato, Tonon, Hubinger, &
133 Cunha, 2012):

$$SG\ \% = \frac{(SS_f \cdot w_f - SS_0 . w_0)}{w_0}$$

134 Where: SS_f is the soluble solid content (° Bx) after osmotic dehydration; w_f is the sample
135 weight after osmotic dehydration (g); SS_0 is the initial soluble solid content (° Bx); w_0 is the
136 sample initial weight (g). Strawberry initial solid content (SS_0) in 10 g (w_0) of fruits was found
137 to be equal to 2.05 ° Bx.
138
139
140

2.8 Rehydration

Rehydration experiments were performed by immersing a weighed amount of dried samples into distilled water at room temperature. The samples were removed at regular intervals, blotted with paper to eliminate the surface water and then reweighed.

Rehydration capacity (RC) was measured for all the samples using the following equation (de Bruijn & Bórquez, 2014):

$$RC = \frac{(w\,(t) - w_d)}{(w_0 - w_d)}\,100$$

Where: w(t) is the sample weight at time t (g) and wd is the dried sample weight (g). Then, the rehydration behaviour was determined plotting RC as a function of the time.

2.9 Texture analysis

A texture analyser (TA.XT plus, Stable Micro System Ltd, Surrey, UK) with a cylinder probe (2 mm diameter) was used for puncture penetration test analysis. The probe was used to measure the maximum force required to penetrate an individual rehydrated piece of strawberry, to a depth of 2 mm, positioned horizontally over a heavy duty platform. The speed of approach of the probe was 2 mm/s and a 5 kg load cell was used. For each experiment the mean maximum penetration force (N) was recorded.

2.10 Confocal scanning laser microscopy

The microstructure of the strawberry samples was visualised at room temperature using a confocal scanning laser microscope (Leica TCS SPE, Heidelberg, Germany) equipped with laser operating at a wavelength of 532 nm. To study how the strawberry structure is affected by drying, samples were first rehydrated and then a cross section with a thickness

163 equal to 1 mm was cut for observation with the microscope. Before imaging, samples slices
164 were stained with Nile red solution and covered with a cover slip.
165
166 2.11 Statistical analysis
167 All measurements were performed in triplicate and are reported as mean and
168 standard deviation. Data were analysed by one-way analysis of variance (ANOVA) and
169 Tukey's multiple comparison tests, using SigmaPlot 12.5 Statistical Software. The level of
170 significance was defined as $p \leq 0.05$.
171
172 **3. Results and discussion**
173 In the first part of the experimentation, an optimisation of the osmotic dehydration
174 operating parameters was carried out in order to identify the conditions that assure the
175 highest water desorption. Afterwards, experiments were performed with oven drying,
176 freeze drying and their combination with osmotic dehydration, in order to verify the
177 effectiveness of the pre-treatment.
178
179 3.1 Osmotic dehydration
180 Osmotic dehydration experiments were carried out investigating the following
181 effects: type of osmotic agent, concentration of the osmotic solution, temperature and
182 processing time. In Table 1, a list of the experiments is reported with the indication of the
183 operating conditions employed, the percentage of moisture content in the pre-treated
184 samples, their water activity and solid gain .
185

186 *3.1.1 Effect of the type of osmotic agent*

187 The first set of experiments was performed at 25 °C, with a fruit to solution ratio
188 (F:OS) equal to 1:10, a processing time equal to 3 h and a concentration of 40 °Bx, varying
189 the kind of osmotic agent, since it has been observed to have a major influence on the mass
190 transfer rate (Atarés, Chiralt, & González-Martínez, 2008). Dehydrators must be effective,
191 convenient, non-toxic, with a good taste and should not react with the product (Yadav &
192 Singh, 2014). In this work, Fructose, Maltose, Sucrose and Maltodextrin were tested as
193 osmotic agents (runs #1-4 in Table 1) in order to investigate which one lead to a more
194 efficient dehydration.

195 Comparing the data obtained from these experiments, it was observed that when
196 Fructose was used as osmotic agent, samples showed the lowest moisture content (58.9
197 g/100 g) and water activity (0.951), as reported in Table 1. Therefore, this osmotic agent
198 was chosen for the further experiments.

199 According to Panagiotou et al. (Panagiotou, Karathanos, & Maroulis, 1999), during
200 osmotic dehydration low molecular weight solutes lead to higher water loss and higher solid
201 uptake than high molecular weight solutes. Our results confirmed their observation since,
202 among the investigated sugars, Fructose has the lowest molecular weight (as shown in Table
203 2) and the soluble solid content, that in the fresh strawberry was equal to 2 °Bx, was
204 increased up to 2.15 % in the samples osmotically treated with this sugar (run #4 in Table 1).

205

206 *3.1.2 Effect of the osmotic solution concentration*

207 The second effect taken into account was the concentration of the osmotic solution,
208 which was varied from 20 to 60 °Bx and compared to 40 °Bx discussed above, keeping
209 constant all the other parameters (runs #5-6 in Table 1). From the comparison of the

obtained results, it was possible to observe that increasing the concentration at 60 °Bx, i.e. increasing the dehydration driving force, the sample solid gain increased up to 3.2 % whereas the moisture content and the water activity significantly decreased. For this reason, it was decided to continue the experimentation fixing the concentration of the osmotic solution at 60 °Bx.

3.1.3 Effect of the operating temperature

The influence of the operating temperature on the osmotic dehydration process was investigated using 35 and 50 °C (runs #7-8 in Table 1). From these experiments, it has been observed that increasing the temperature the dehydration efficiency increased, reaching a moisture content equal to 18.77 g/100 g and a water activity equal to 0.705 at 50 °C and 3 h processing. This result is due to an increase of the cell membrane permeability and a reduction of the osmotic solution viscosity at higher temperature, which cause a decrease in the resistance to mass transfer (de Oliveira, Corrêa, de Angelis Pereira, de Lemos Souza Ramos, & Vilela, 2016). As a consequence, the solid gain also increased since there is a larger amount of sugar that flows from the solution towards the sample.

3.1.4 Effect of the processing time

During osmotic dehydration, water diffusion rate from the product is fast in the first few hours, thereafter it gradually decrease until the achievement of a plateau value; at the same time, when moisture loss lowers, the solute intake rate towards the product increases (Ahmed, Qazi, & Jamal, 2016). Therefore, it is very important to identify the appropriate processing time in order to find a good compromise between water desorption and solid uptake.

234 The influence of the processing time was studied performing experiments at 1 and 5
235 h (runs #9 and #10, respectively). Using a processing time of 1 h, the final moisture content
236 was 3.5 times larger than the MC obtained at 3 h (run #8), as reported in Table 1. On the
237 other hand, the use of a processing time equal to 5 h led to a higher water desorption;
238 however, from a technological point of view, the improvement is not as significant as to
239 justify the employment of such a long process. Moreover, the solid gain measured at this
240 condition was much higher than that of run #8.
241 On the ground of the optimisation of the process parameters, the chosen conditions
242 for the further dehydration experiments were those of run #8, i.e. Fructose as osmotic
243 agent, temperature of50 °C, concentration equal to 60 °Bx and processing time equal to 3 h.
244
245 3.2 Oven drying
246 Conventional drying tests were carried out studying the effects of the operating
247 temperature and the processing time.
248
249 *3.2.1 Effect of the operating temperature*
250 In a first step, experiments were performed with a processing time equal to 5 h, at
251 different operating temperatures, in order to determine the best condition for drying. In
252 Table 3, a list of the experiments with the corresponding conditions and results is reported.
253 When the oven temperature was fixed at 40 °C (run #1 in Table 3), it was observed
254 only a slight reduction of the sample moisture content and the water activity compared to
255 the fresh sample. At 50 °C (run #2 in Table 3), a further improvement of the results was
256 observed. At 60 °C (run #3 in Table 3), the reduction of the moisture content was more
257 evident but the samples, from a macroscopic point of view, appeared partially melted.

258 However, in all the cases, the samples' water activity was still high; therefore, longer
259 processing times might be required to achieve the threshold value to avoid microbial
260 proliferation (Stevenson et al., 2015).
261
262 *3.2.2 Effect of the processing time*
263 In order to identify the processing time needed to obtain a MC lower than 20 g/100
264 g, the evolution of the moisture content was monitored as function of the time at 50 °C, as
265 shown in Fig. 1.
266 As shown in Fig. 1, about 8 h of processing are needed to achieve a MC equal to 13
267 g/100 g. However, after 6 h the samples' structure was completely destroyed with a
268 complete change in their shape and texture.
269 On the basis of these results, it is possible to conclude that oven drying cannot be
270 considered an effective drying technique for strawberry processing. In order to improve the
271 performance of this process, the osmotic dehydration pre-treatment was then applied.
272
273 *3.2.3 Osmotic dehydration+ Oven drying*
274 The best conditions identified from osmotic dehydration experiments (run #8 in
275 Table 1) were fixed for the pre-treatment; samples were then processed using oven drying
276 at 50 °C over a period of 2 h (run #4 in Table 3). At the end of the experiment, the moisture
277 content was significantly reduced to 6.7 g/100 g and the water activity was reduced to
278 0.437; both the values were below the required threshold to avoid microbial spoilage.
279 Comparing this result with that of run #2 (Table 3), it is possible to deduce that using
280 the same processing time (5 h), the combination of the two techniques provided a more
281 efficient result with respect to the only oven drying.

282 3.3 Freeze drying

283 Freeze drying experiments were performed at different processing time, as shown in
284 Fig. 2a and 2b, where the final moisture content and the water activity were plotted as a
285 function of the time. From these diagrams, it can be seen that presumably at least 15 h are
286 necessary to reach acceptable values from a microbiological point of view. In order to
287 reduce the processing time, the combination osmotic dehydration + freeze drying was
288 investigated.

289

290 *3.3.1 Osmotic dehydration + freeze drying*

291 For the osmotic dehydration the conditions of run #8 in Table 1 were chosen as the
292 pre-treatment. For freeze drying, two processing times were investigated, as shown in Table
293 4 (runs #3-4).

294 Fixing the freeze drying processing time at 4 h (run #3 in Table 4), the moisture
295 content reduced slightly with respect to the only osmotic dehydration (run #8 in Table 1),
296 but the water activity value reduced significantly. Comparing this result with those obtained
297 with the only freeze drying, it can be observed that the combination of the two techniques
298 allows the total processing time to be reduced from 15 h to 7 h.

299 Increasing the freeze drying processing time to 7 h (run #4 in Table 4), showed a
300 large reduction of the MC and a_w. This result, obtained with a total processing time of 10 h,
301 can be reached in 18 h using the only freeze drying (run #2 in Table 4). Therefore, osmotic
302 pre-treatment has been shown to be an effective way to significantly reduce the processing
303 time and, as a consequence, the related energetic costs.

304

305

306 3.4 Rehydration behaviour

307 As already discussed in the *Introduction,* rehydration is a fundamental aspect in
308 drying process. In this phenomenon different physical mechanisms are involved: absorption
309 of water into the dried product, diffusion of water molecules through the porous network
310 and swelling (Ratti, 2008). The degree of rehydration is mainly influenced by the employed
311 drying process since it affects the integrity of the food structure.

312

313 *3.4.1 Oven drying*

314 In Fig. 3, the comparison between the rehydration behaviour of the oven drying and
315 osmotic dehydration+ oven dried samples is reported. When rehydrated, osmotic dried
316 samples reached a RC equal to 15.9 g/100 g; whereas osmotic dehydration+ oven dried
317 samples showed a relevant improvement of the rehydration capacity, achieving a value
318 equal to 30.7 g/100 g. This is a further evidence of the effectiveness of the osmotic pre-
319 treatment when applied to oven drying.

320

321

322 *3.4.2 Freeze drying*

323 In Fig. 4, a comparison between the rehydration behaviour of the freeze dried and
324 the osmotic dehydration + freeze dried samples is reported.

325 From these rehydration tests it is possible to observe that freeze dried samples
326 reached a rehydration capacity around 42 g/100 g, whereas pre-treated samples reached a
327 lower RC, equal to 30 g/100 g. This experimental evidence was already observed by some

328 authors (Ciurzyńska & Lenart, 2012; Seguí, Fito, & Fito, 2013); it could be due to the
329 sample's shrinkage that occurs during the treatment which makes water absorption more
330 difficult and slow.
331 In this case the pre-treatment had a detrimental effect on samples' rehydration
332 ability when applied to freeze drying. However, these dried products could be used in
333 applications in which rehydration is not necessarily required such as snacks and cereal mix.
334
335 3.5 Texture analyses
336 Texture is one of the most important quality criteria for food acceptability by
337 consumers, especially for dried products. In this work, puncture penetration test was used
338 as an indicator of strawberry textural properties; the analyses were carried out on fresh and
339 rehydrated samples. The results of the tests in terms of maximum penetration force for
340 each drying technique are shown in Fig. 5. The analyses revealed that drying process caused
341 a decrease in strawberry firmness, independently from the used technique. Comparing the
342 results of the different methods, it was found that textural properties were better retained
343 when osmotic pre-treatment was applied. Texture is less preserved in oven dried samples
344 since this technique caused a collapse of the microstructure with consequent softening of
345 the macrostructure. Freeze dried samples, instead, showed intermediate results between
346 pre-treated and oven dried samples.
347
348 3.6 Microstructure analyses
349 Strawberry has a complex internal structure, formed by many tissues which have
350 different chemical composition and microstructure. The skeleton of this fruit is composed by
351 the vascular tissue which is composed of long fibre and pith. The outer layer is formed by

epidermal cells; the inner layer is formed by hypodermal cells and cortical cells (Polito, Larson, & Pinney, 2002). In each cell it is possible to identify the intercellular volume, which contains vacuole and cytoplasm, and the extracellular volume, which comprises the cell membrane and the space between different cells. In order to localize cell membranes, samples were stained with Neil Red since it has the ability to bind to its phospholipids (Fujimura et al., 2007). Fig. 6 shows the cortex cells in fresh and rehydrated strawberries observed with the confocal scanning laser microscope.

As observed in Fig. 6a, unprocessed strawberry cells are 100's of μm and close to each other. In freeze dried and osmotic dehydration + freeze dried samples, shown in Fig. 6b and 6c respectively, the cells are still clearly visible which means that the processing did not affect the sample microstructure; moreover, in both the cases, they are smaller probably because samples were not able to reach the complete rehydration in the time of the study, as it was previously discussed. In the case of oven dried sample (Fig. 6d) it was not possible to identify cells since the sample microstructure was completely destroyed. When osmotic dehydration is applied prior to oven drying, the collapse of the structure is partially limited and some cells are still present even if broken in some points; this result explains why in these samples rehydration is higher than that of the oven dried samples.

4. Conclusions

In this work the influence of osmotic dehydration on oven and freeze drying performance has been carried out. It has been demonstrated that the application of the pre-treatment allows: a significant reduction the processing time and a better retention of the mechanical and structural properties of strawberry; to improve the rehydration ability in the case of oven dried samples.

These results can be relevant from an industrial point of view since they allow a better understanding of the physical processes and could lead to a reduction in cost and improvement in the quality of the product.

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Figures

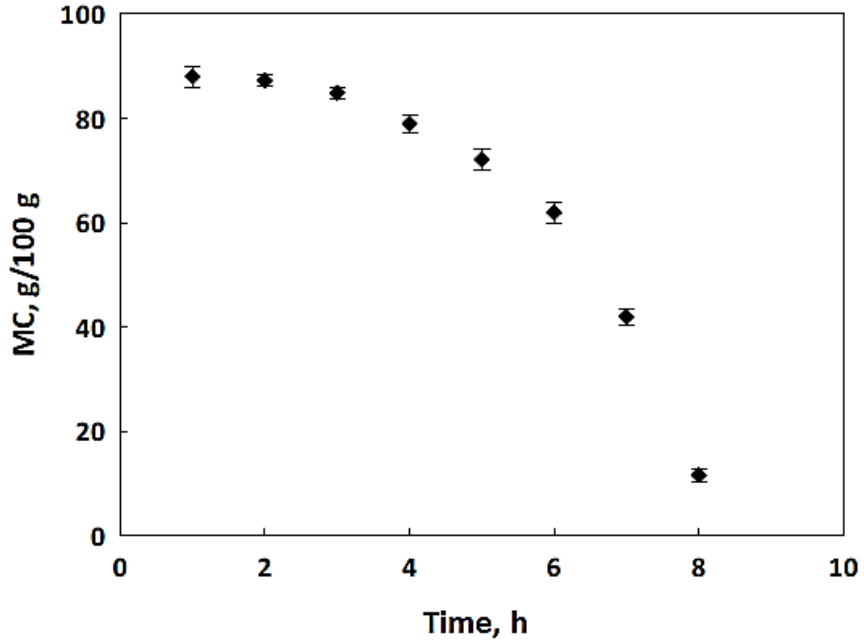
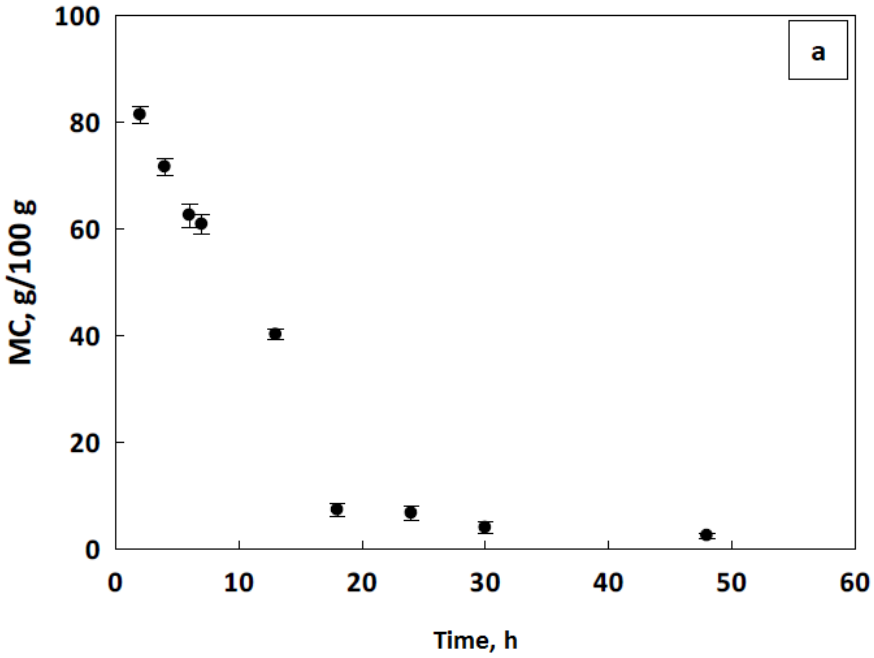
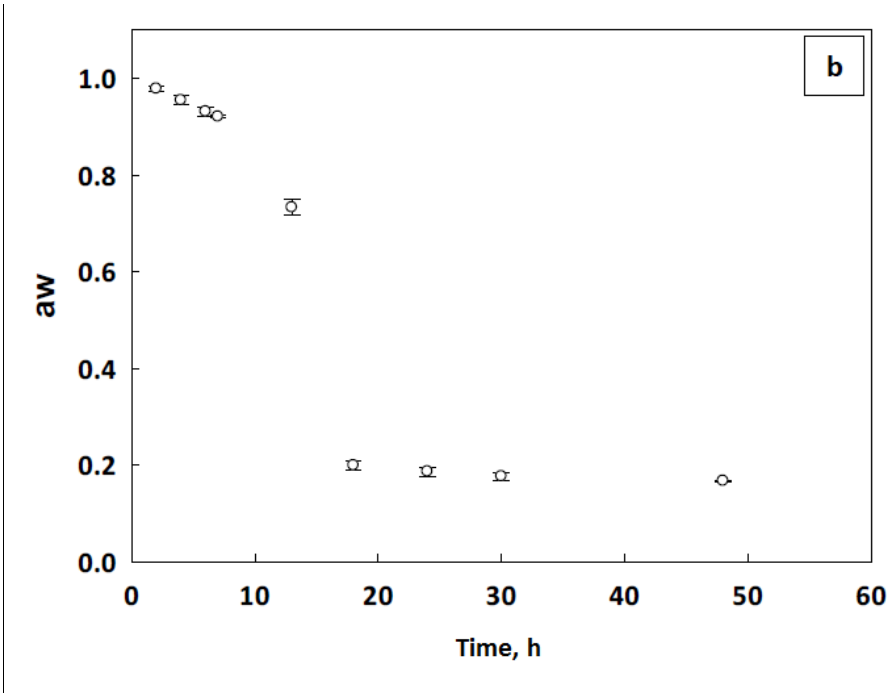


Fig. 1: Moisture content (MC) evolution during oven drying at 50 °C. Each value is expressed as mean ± SD (n=3), statistical significance was assessed by one-way ANOVA.





460

461 **Fig. 2:** Evolution over the time of: (a) Moisture content (MC); (b) Water activity (a_W).

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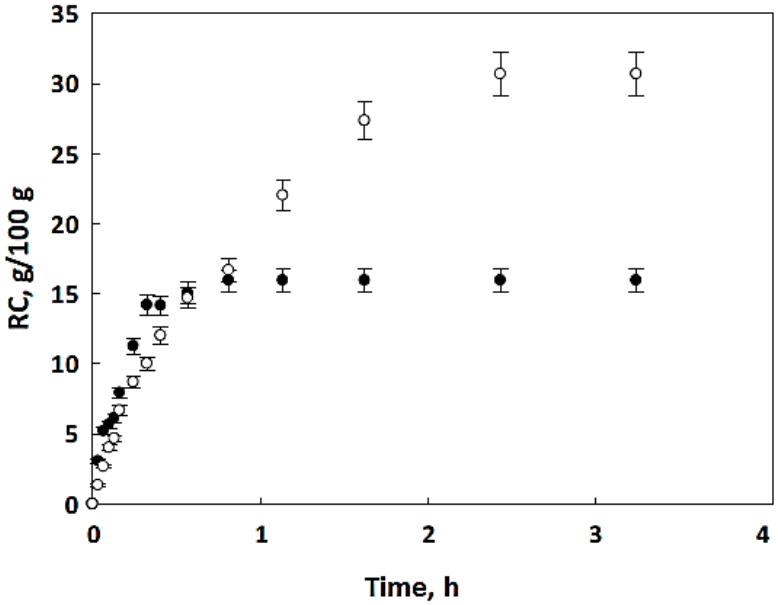

463

464 **Fig. 3:** Comparison between the rehydration behaviour of oven dried and osmotic
465 dehydration + oven dried samples: ● oven drying; ○ osmotic dehydration +oven drying; RC:
466 rehydration capacity.
467

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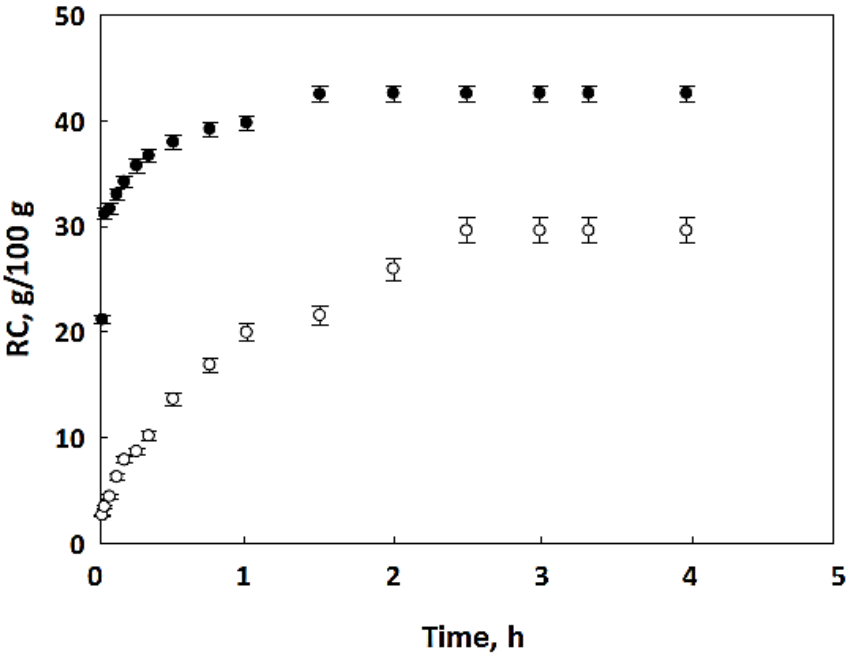
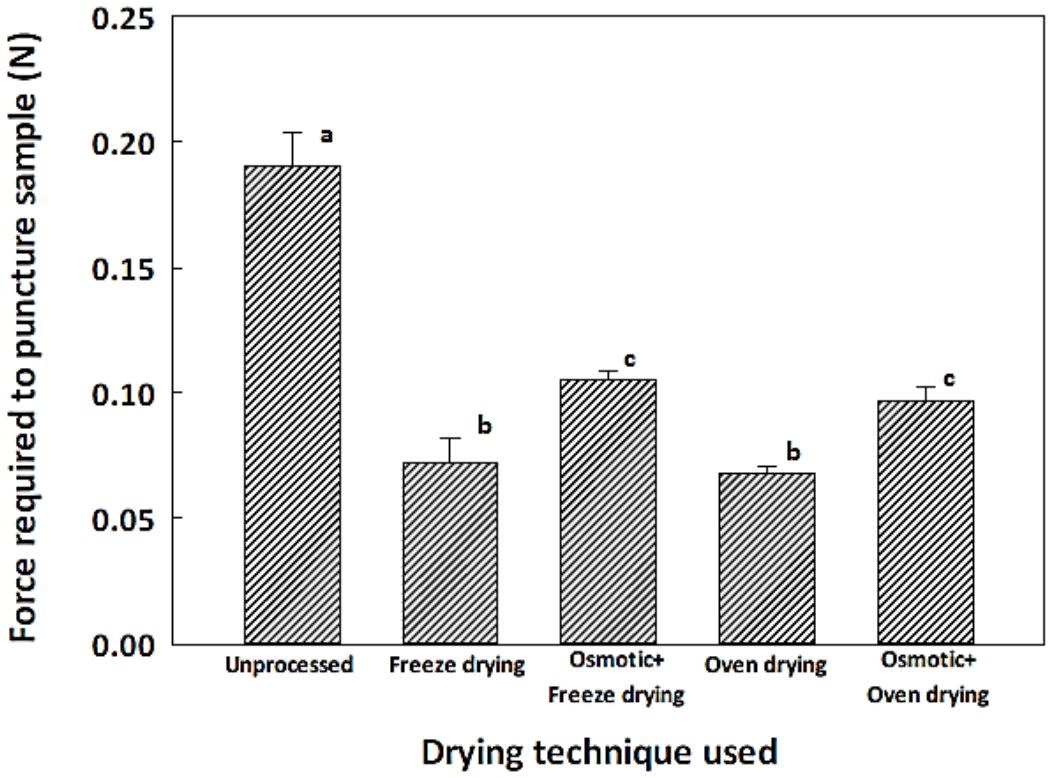


469

470 **Fig. 4:** Comparison between the rehydration behaviour of freeze dried and osmotic
471 dehydration + freeze dried samples: ● freeze drying; ○ osmotic dehydration +freeze drying;
472 RC: rehydration capacity.
473

474



475

Fig. 5: Puncture penetration testing of strawberries dried using different techniques and rehydrated at room temperature. Each value is expressed as mean ± SD (n=3). The values followed by the same letter (abc) are not significantly different according to one-way ANOVA and Tukey's multiple comparison tests.

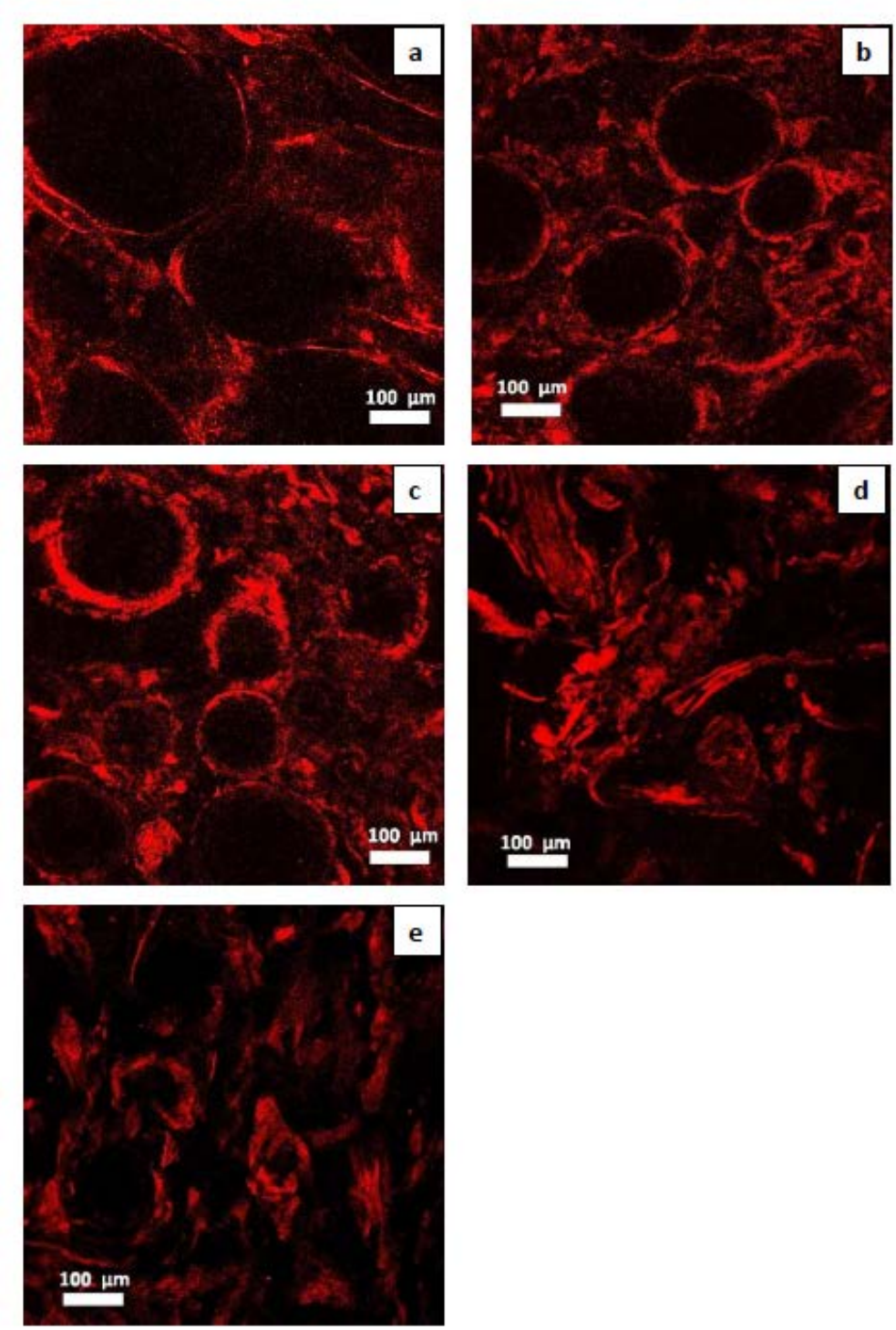


Fig. 6: Confocal microscope images of strawberry cortex cells: (a) unprocessed sample; (b) freeze dried sample; (c) osmotic+freeze dried sample; (d) oven dried sample; (e) osmotic+oven dried sample.

TABLES

Table 1: Summary of the osmotic dehydration experiments. Each value is expressed as mean ± SD (n=3). The values followed by the same letter (abcdefghi) in the columns are not significantly different according to one-way ANOVA and Tukey's multiple comparison tests.

#	Osmotic agent	C [°Bx]	T [°C]	t [h]	MC [g/100 g]	a_w	SG % [°Bx]
1	Maltodextrin	40	25	3	75.91 ± 0.82^{a}	0.985 ± 0.003^{a}	1.03 ± 0.03^{a}
2	Sucrose	40	25	3	70.53 ± 1.90^{b}	0.957 ± 0.006^{b}	1.78 ± 0.04^{b}
3	Maltose	40	25	3	71.70 ± 1.40^{b}	$0.960\pm0.004^{b,c}$	1.75 ± 0.05^{b}
4	Fructose	40	25	3	58.90 ± 1.46^{c}	$0.951\pm0.003^{b,c}$	2.15 ± 0.06^{c}
5	Fructose	20	25	3	76.70 ± 1.15^{a}	$0.974\pm0.006^{a,c}$	1.97 ± 0.02^{d}
6	Fructose	60	25	3	44.60 ± 1.45^{d}	0.910 ± 0.003^{d}	3.20 ± 0.03^{e}
7	Fructose	60	35	3	31.84 ± 0.92^{e}	0.780 ± 0.005^{e}	3.47 ± 0.03^{f}
8	Fructose	60	50	3	18.77 ± 1.06^{f}	0.705 ± 0.003^{f}	4.22 ± 0.02^{g}
9	Fructose	60	50	1	67.83 ± 1.25^{b}	$0.966\pm0.009^{b,c}$	1.69 ± 0.05^{h}
10	Fructose	60	50	5	18.10 ± 1.13^{f}	0.695 ± 0.007^{f}	4.34 ± 0.04^{i}

C*:* concentration of the osmotic solution; T: temperature; t: processing time; MC: moisture content; a_w: water activity; SG: solid gain

Table 2: Osmotic agents' molecular weight.

Osmotic agent	Molecular weight [g/mol]
Maltodextrin	957.5
Sucrose	342.3
Maltose	342.3
Fructose	180.2

Table 3: Oven drying and osmotic dehydration+oven drying experiments. Each value is expressed as mean ± SD (n=3). The values followed by the same letter (abcd) in the columns are not significantly different according to one-way ANOVA and Tukey's multiple comparison tests.

#	Process	T [°C]	MC [g/100 g]	a_w
1	Oven drying	40	80.1 ± 2.06^{a}	0.978 ± 0.008^{a}
2	Oven drying	50	75.6 ± 1.51^{b}	$0.966\pm0.008^{a,b}$
3	Oven drying	60	66.4 ± 1.75^{c}	0.958 ± 0.005^{b}
4	Osmotic+oven drying	50	6.7 ± 0.47^{d}	0.437 ± 0.004^{c}

T: temperature; MC: moisture content; a_w: water activity

Table 4: Freeze drying and osmotic dehydration+freeze drying experiments. Each value is expressed as mean ± SD (n=3) .The values followed by the same letter (abc) in the columns are not significantly different according to one-way ANOVA and Tukey's multiple comparison tests.

#	Process	Time [h]	MC [g/100 g]	a_w
1	Freeze drying	7	61.04±1.11[a]	0.920±0.007[a]
2	Freeze drying	18	7.38±0.80[b]	0.195±0.007[b]
3	Osmotic+Freeze drying	(3)+4	15.34±0.96[c]	0.461±0.003[c]
4	Osmotic+Freeze drying	(3)+7	7.52±0.79[b]	0.195±0.006[b]

MC: moisture content; a_w: water activity