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

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1 **Influence of osmotic dehydration pre-treatment on oven drying and**

2 **freeze drying performance**

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7 **Abstract**

8 Drying is largely used in food industry, since it allows prolonging the product shelf

9 life by inhibiting microorganisms' growth and enzyme activity. Traditional drying techniques,

10 such as air drying and freeze drying, suffer from several drawbacks, mainly long processing

11 time, low rehydration capacity and change in food properties. Some pre-treatments, such as

12 osmotic dehydration, can be applied prior to conventional techniques in order to produce

13 an intermediate moisture product and, therefore, to improve the drying process. In this

14 work, the influence of osmotic dehydration on oven drying and freeze drying performance

15 was evaluated. Firstly, the effects of the main osmotic dehydration parameters were

16 investigated in order to find the best conditions for water desorption. Secondly,

17 experiments with oven drying, freeze drying and their combination with osmotic pre-

18 treatment were carried out. Results of each technique in terms of final moisture content,

19 water activity, rehydration ability, textural properties and microstructure were compared

20 and discussed. It has been observed that the application of the pre-treatment allows

21 reducing considerably the processing time and better retaining the food properties.

22

23 **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

72 achieve a pear final moisture content of 0.25 kg/kg dry solids; however, they did not report

73 the samples' final water activity and rehydration capacity. Patil et al. (Patil, Kalse, & Jain,

74 2012) also observed that the application of the pre-treatment to convective drying allowed

75 to reduce onion drying time by approximately 40 % but the effect on samples' water activity

76 and microstructure was omitted. Ruiz-López at al. (Ruiz-López, Huerta-Mora, Vivar-Vera,

77 Martínez-Sánchez, & Herman-Lara, 2010) pointed out that the osmotic dehydration pre-

78 treatment led to a significant decrease in chayote moisture content, allowing to reduce air-

79 drying time up to 65 % depending on the used dehydrator; however, also in this case,

80 information about water activity, rehydration ability and structural properties were missing.

81 In the present work, osmotic dehydration was applied prior to oven drying and

82 freeze drying in order to improve their performances. The model food chosen for the

83 experimentation was strawberry, since it is one of the most consumed fruits, thanks to its

84 enjoyable organoleptic characteristics and its healthy properties. First, an optimisation of

85 the pre-treatment operating conditions was carried out in order to identify the best

86 conditions for the highest water desorption. Several experiments were then performed

87 using oven drying, osmotic dehydration + oven drying, freeze drying and osmotic

88 dehydration + freeze drying. The results in terms of samples' final moisture content, water

89 activity, rehydration ability and quality retention were compared and discussed.

90 **2. Materials and methods**

91 2.1 Materials

92 Fructose (purity ≥ 99 %), Maltodextrin (purity ≥ 99.5 %), Maltose (purity ≥ 95 %) and

93 Sucrose (purity ≥ 99.5 %) were supplied by Sigma Aldrich (UK). All materials were used as

94 received. Fresh strawberries (*Malling centenary*) were purchased by a local supermarket

95 and stored in a refrigerator at 5 °C. After washing in tap water and draining with blotting

96 paper, strawberries were cut into cubes of 1 cm^3.

97

98 2.2 Osmotic dehydration

99   Osmotic dehydration experiments were carried out by immersion of 10 g of

100 strawberry cubes in the osmotic solution, at fixed temperature, under stirring at 250 rpm.

101 The fruit to solution ratio (F:OS) was fixed at 1:10. At the end of each experiment, samples

102 were taken and blotted with paper.

103

104 2.3 Oven drying

105   Conventional drying tests were carried out introducing strawberry cubes in an oven

106 (Fistreem International Co. Ltd, Leicestershire, UK) with no flow air, at room pressure and

107 fixed temperature.

108

109 2.4 Freeze drying

110   Fresh cubic samples were frozen at -20 °C and then lyophilised using a bench top

111 Freeze Dryer (SCANVAC Coolsafe^{TM}, model 110-4, Lynge, Denmark), condenser

112 temperature-110 °C, pressure 10 Pa.

113

114 2.5 Moisture content analysis

115   Moisture content (MC) analyses were carried out using a moisture analyser (model

116 MB 25, OHAUS, Nanikon, Switzerland). Two grams of sample were placed within the

117 aluminium pans and located over the pan support of moisture meter. Halogen element

118 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

141   2.8 Rehydration

142   Rehydration experiments were performed by immersing a weighed amount of dried

143   samples into distilled water at room temperature. The samples were removed at regular

144   intervals, blotted with paper to eliminate the surface water and then reweighed.

145   Rehydration capacity (RC) was measured for all the samples using the following

146   equation (de Bruijn & Bórquez, 2014):

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

147   Where: w(t) is the sample weight at time t (g) and wd is the dried sample weight (g). Then,

148   the rehydration behaviour was determined plotting RC as a function of the time.

149

150   2.9 Texture analysis

151   A texture analyser (TA.XT plus, Stable Micro System Ltd, Surrey, UK) with a cylinder

152   probe (2 mm diameter) was used for puncture penetration test analysis. The probe was

153   used to measure the maximum force required to penetrate an individual rehydrated piece

154   of strawberry, to a depth of 2 mm, positioned horizontally over a heavy duty platform. The

155   speed of approach of the probe was 2 mm/s and a 5 kg load cell was used. For each

156   experiment the mean maximum penetration force (N) was recorded.

157

158   2.10 Confocal scanning laser microscopy

159   The microstructure of the strawberry samples was visualised at room temperature

160   using a confocal scanning laser microscope (Leica TCS SPE, Heidelberg, Germany) equipped

161   with laser operating at a wavelength of 532 nm. To study how the strawberry structure is

162   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

210 obtained results, it was possible to observe that increasing the concentration at 60 °Bx, i.e.

211 increasing the dehydration driving force, the sample solid gain increased up to 3.2 %

212 whereas the moisture content and the water activity significantly decreased. For this

213 reason, it was decided to continue the experimentation fixing the concentration of the

214 osmotic solution at 60 °Bx.

215

216 *3.1.3 Effect of the operating temperature*

217   The influence of the operating temperature on the osmotic dehydration process was

218 investigated using 35 and 50 °C (runs #7-8 in Table 1). From these experiments, it has been

219 observed that increasing the temperature the dehydration efficiency increased, reaching a

220 moisture content equal to 18.77 g/100 g and a water activity equal to 0.705 at 50 °C and 3 h

221 processing. This result is due to an increase of the cell membrane permeability and a

222 reduction of the osmotic solution viscosity at higher temperature, which cause a decrease in

223 the resistance to mass transfer (de Oliveira, Corrêa, de Angelis Pereira, de Lemos Souza

224 Ramos, & Vilela, 2016). As a consequence, the solid gain also increased since there is a

225 larger amount of sugar that flows from the solution towards the sample.

226

227 *3.1.4 Effect of the processing time*

228   During osmotic dehydration, water diffusion rate from the product is fast in the first

229 few hours, thereafter it gradually decrease until the achievement of a plateau value; at the

230 same time, when moisture loss lowers, the solute intake rate towards the product increases

231 (Ahmed, Qazi, & Jamal, 2016). Therefore, it is very important to identify the appropriate

232 processing time in order to find a good compromise between water desorption and solid

233 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 of 50 °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

352   epidermal cells; the inner layer is formed by hypodermal cells and cortical cells (Polito,

353   Larson, & Pinney, 2002). In each cell it is possible to identify the intercellular volume, which

354   contains vacuole and cytoplasm, and the extracellular volume, which comprises the cell

355   membrane and the space between different cells. In order to localize cell membranes,

356   samples were stained with Neil Red since it has the ability to bind to its phospholipids

357   (Fujimura et al., 2007). Fig. 6 shows the cortex cells in fresh and rehydrated strawberries

358   observed with the confocal scanning laser microscope.

359   As observed in Fig. 6a, unprocessed strawberry cells are 100's of μm and close to

360   each other. In freeze dried and osmotic dehydration + freeze dried samples, shown in Fig. 6b

361   and 6c respectively, the cells are still clearly visible which means that the processing did not

362   affect the sample microstructure; moreover, in both the cases, they are smaller probably

363   because samples were not able to reach the complete rehydration in the time of the study,

364   as it was previously discussed. In the case of oven dried sample (Fig. 6d) it was not possible

365   to identify cells since the sample microstructure was completely destroyed. When osmotic

366   dehydration is applied prior to oven drying, the collapse of the structure is partially limited

367   and some cells are still present even if broken in some points; this result explains why in

368   these samples rehydration is higher than that of the oven dried samples.

4. Conclusions

370   In this work the influence of osmotic dehydration on oven and freeze drying

371   performance has been carried out. It has been demonstrated that the application of the pre-

372   treatment allows: a significant reduction the processing time and a better retention of the

373   mechanical and structural properties of strawberry; to improve the rehydration ability in the

374   case of oven dried samples.

375   These results can be relevant from an industrial point of view since they allow a better

376   understanding of the physical processes and could lead to a reduction in cost and

377   improvement in the quality of the product.

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Figures

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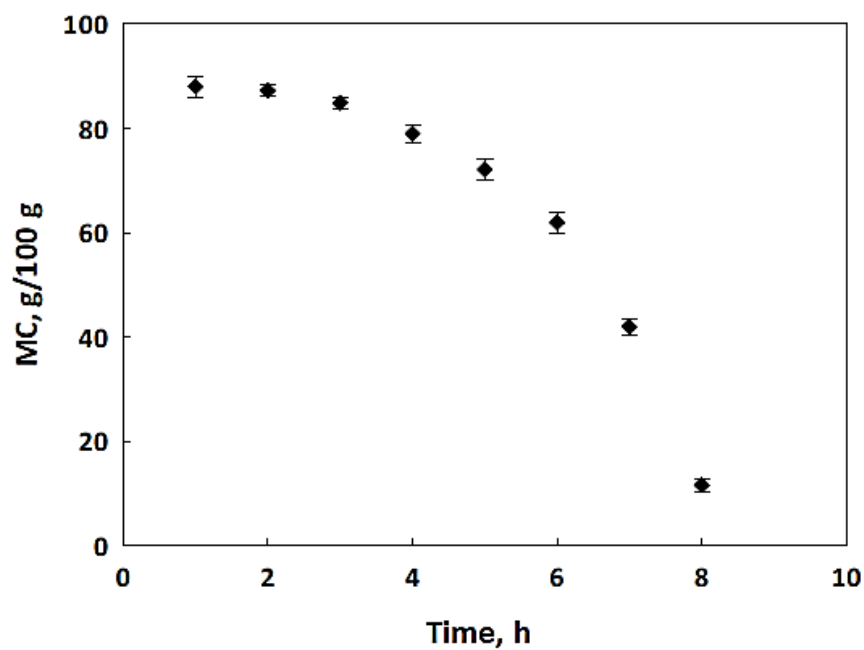
Fig. 1: Moisture content (MC) evolution during oven drying at 50 °C. Each value is expressed as mean ± SD (n=3), statistical significance was assessed by one-way ANOVA.
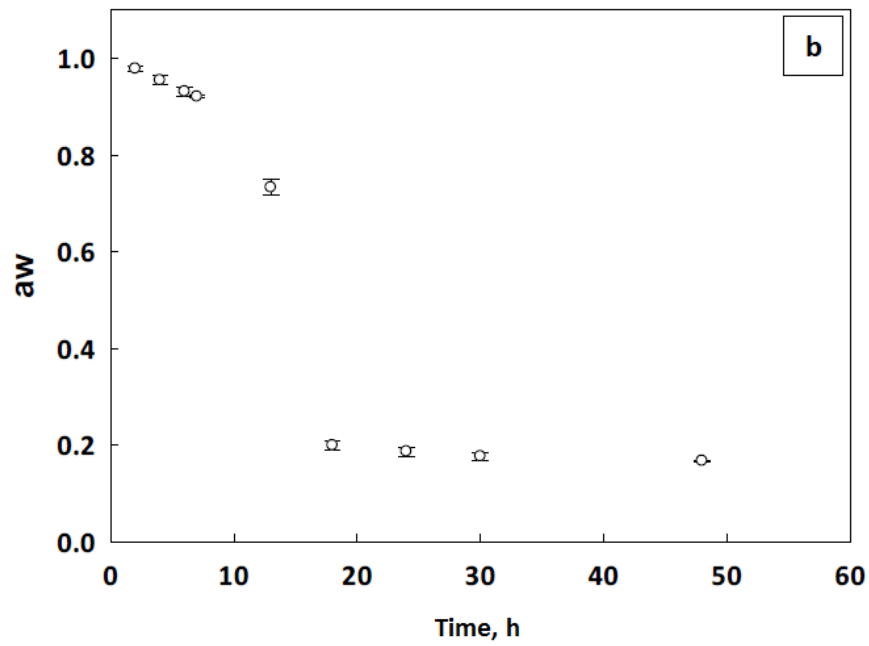
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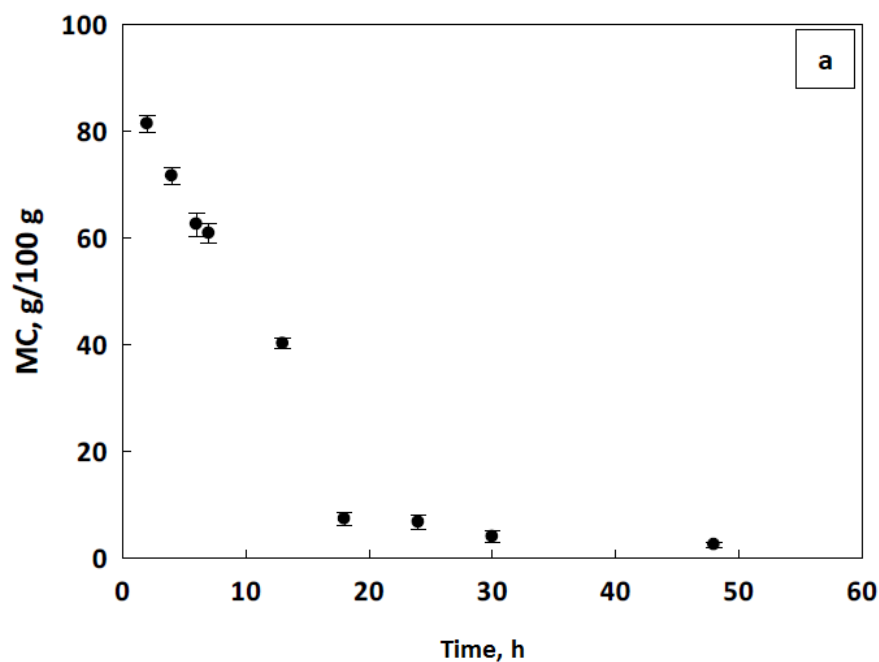
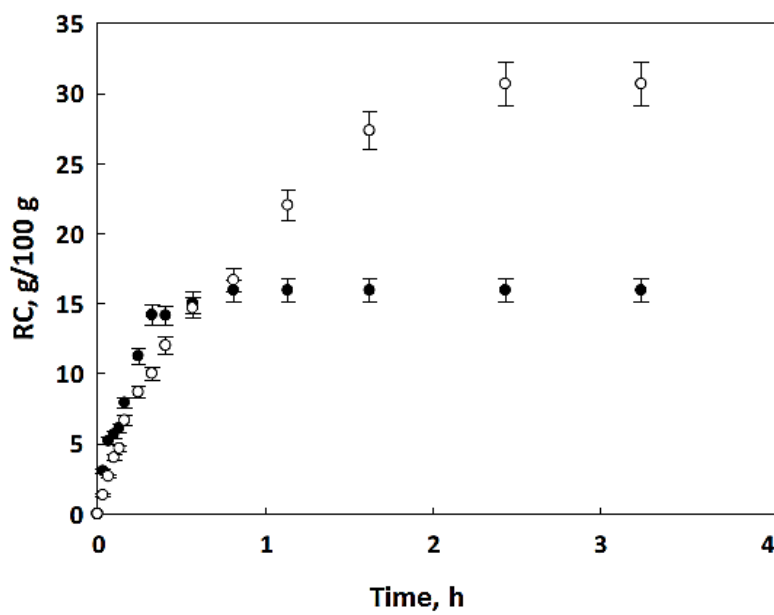461   **Fig. 2:** Evolution over the time of: (a) Moisture content (MC); (b) Water activity (a_W).

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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:
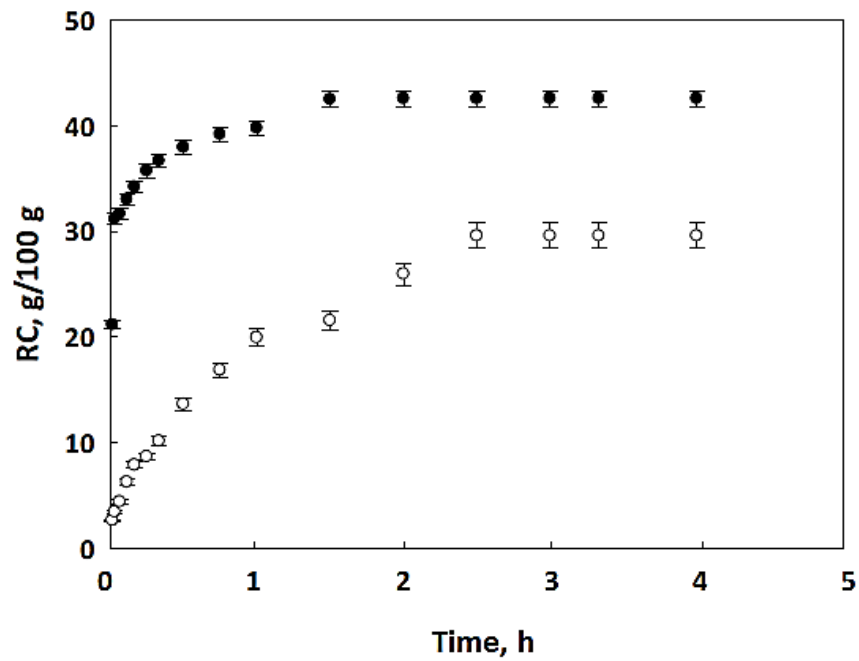466   rehydration capacity.

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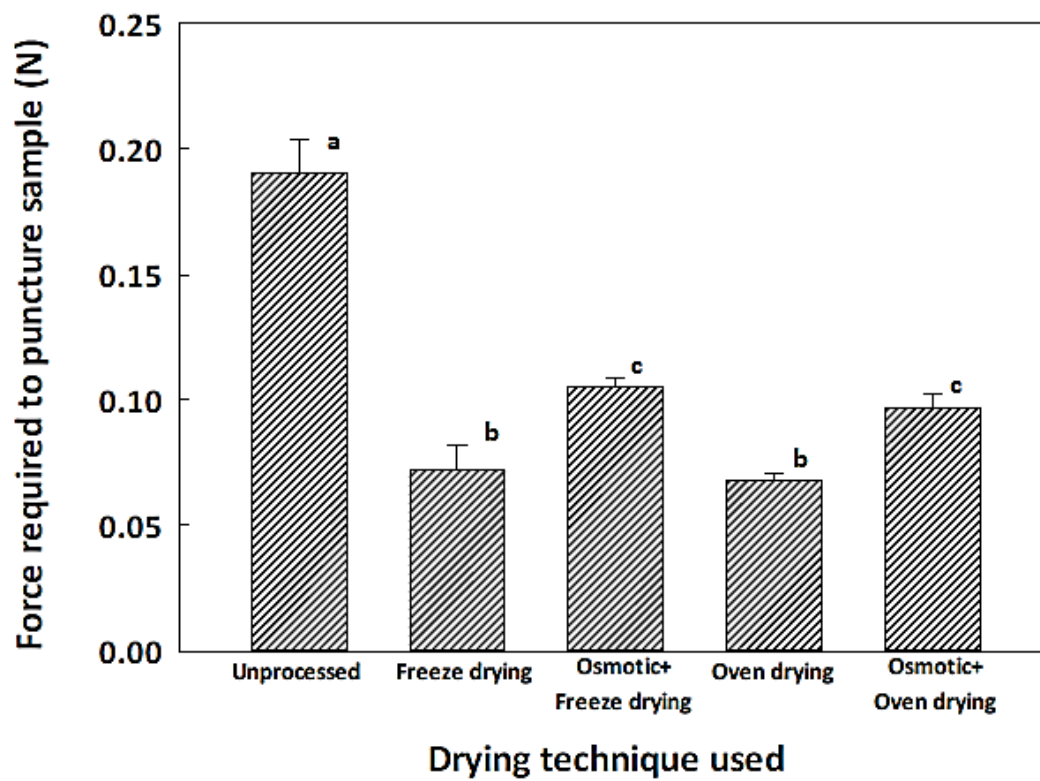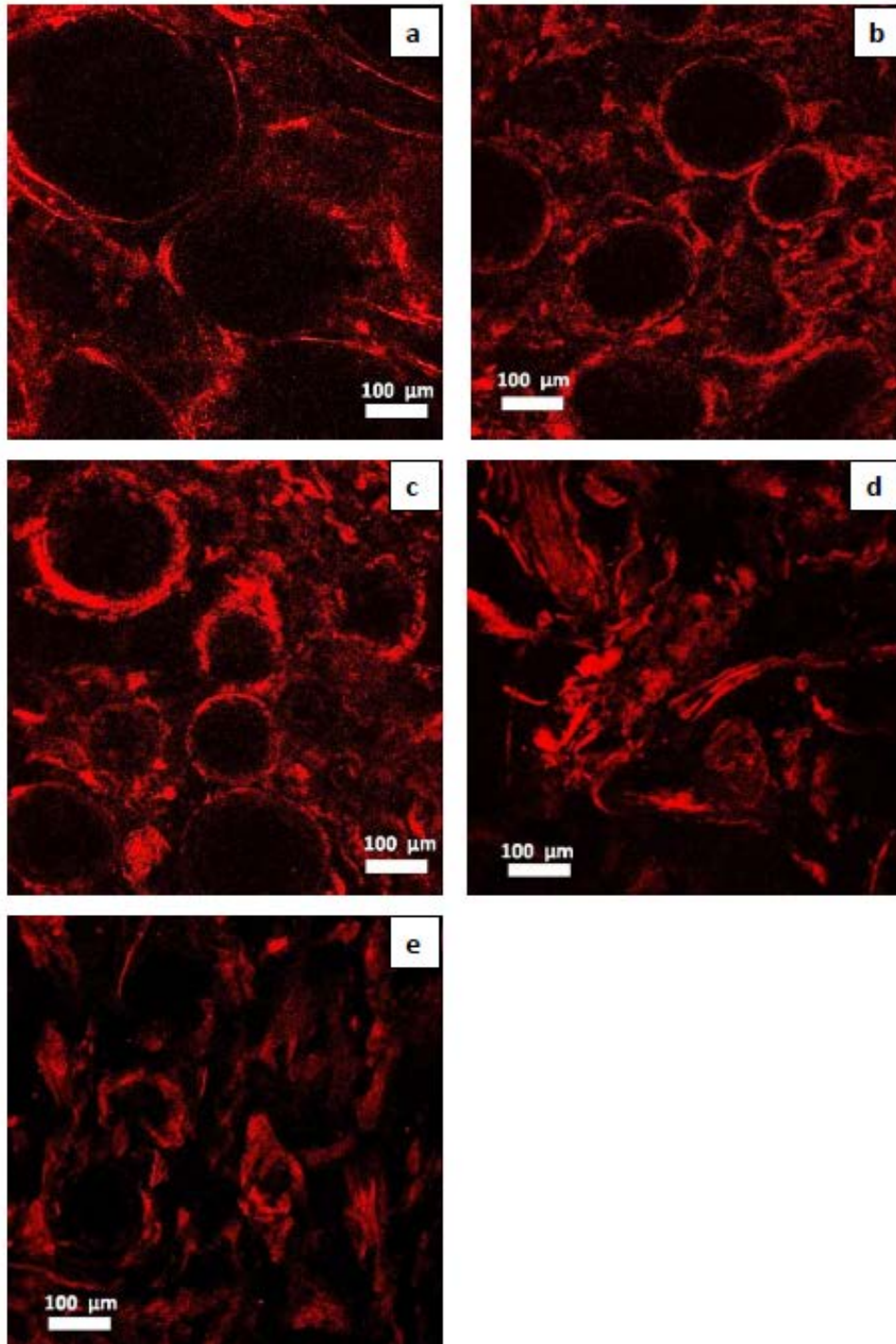RC: rehydration capacity.

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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±0.004[b,c]	1.75±0.05[b]
4	Fructose	40	25	3	58.90±1.46[c]	0.951±0.003[b,c]	2.15±0.06[c]
5	Fructose	20	25	3	76.70±1.15[a]	0.974±0.006[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±0.009[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±0.008[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

503 **Table 4**: Freeze drying and osmotic dehydration+freeze drying experiments. Each value is
504 expressed as mean ± SD (n=3) .The values followed by the same letter (abc) in the columns
505 are not significantly different according to one-way ANOVA and Tukey's multiple
506 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

507 MC: moisture content; a_w: water activity
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