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# Accepted Manuscript

Effect of pulsed electric field (PEF) pre-treatment coupled with osmotic dehydration on physico-chemical characteristics of organic strawberries

Urszula Tylewicz, Silvia Tappi, Cinzia Mannozi, Santina Romani, Nicolò Dellarosa, Luca Laghi, Luigi Ragni, Pietro Rocculi, Marco Dalla Rosa



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**Highlights**

- Organic strawberries were used to obtain semi-dried osmodehydrated products.
- PEF prior OD positively affected the mass transfer even at the lowest intensity.
- At low PEF ( $100 \text{ V cm}^{-1}$ ) cell viability was partially preserved.
- Sucrose and trehalose solutions exerted a similar effects on the studied parameters.

1 Effect of pulsed electric field (PEF) pre-treatment coupled with osmotic dehydration on physico-  
2 chemical characteristics of organic strawberries

3  
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26 **Abstract**

27 The aim of this work was to evaluate the effect of pulsed electric field (PEF) pre-treatment on mass  
28 transfer phenomena, water distribution and some physico-chemical parameters of osmo-dehydrated  
29 organic strawberries. For PEF treatments 100 near-rectangular shaped pulses, with fixed pulse width of  
30 100  $\mu\text{s}$  and repetition time of 10 ms were used. Electric fields strength applied were 100, 200 and 400  
31  $\text{V cm}^{-1}$ . Afterwards, samples were subjected to OD treatments carried out in two different hypertonic  
32 solutions (40% w/w), one with sucrose and the other one with trehalose. The results shown that PEF  
33 treatment positively affected the mass transfer during OD even at the lowest electric field strength  
34 applied (100  $\text{V/cm}$ ), partially preserving the cell viability and maintaining at the same time the fresh-  
35 like characteristics of strawberries.

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38 **Keywords:** fruit quality, strawberries, organic, texture, colour, non-thermal treatment

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## 51 1. Introduction

52 Increased consumer demand for safety, health and environmental friendly food products make the  
53 organic production one of the fastest growing market segments over the last few years. Consumers  
54 expect the quality of organic fruits to be higher or at least comparable with the conventionally  
55 produced ones, protecting at the same time the nature and reducing the environmental pollution  
56 (Barański et al., 2014).

57 Berries, and in particular strawberries, are very attractive for consumers, because of their unique  
58 flavour, texture and red vivid colour, both in a fresh form and in a variety of food products and snacks.  
59 They are also highly appreciated by consumers due to their high amount of ascorbic acid and  
60 antioxidants (Velickova et al., 2013; Gamboa-Santos et al., 2014). However strawberries are highly  
61 susceptible to mechanical injury and also highly perishable (Badawy et al., 2016; Kadivec et al.,  
62 2016); these characteristics could be even more pronounced in the organic fruit. Therefore, there is a  
63 need to improve the processing of these fruits in order to obtain semi-dried or intermediate moisture  
64 products with longer shelf-life. With regards to organic production practices, applied treatments and  
65 processes should be aimed at avoiding the chemical additives, while non-thermal processing are used  
66 with the aim of maintaining the nutritional and sensorial properties of food products.

67 Osmotic dehydration (OD) is one of the non-thermal processes used to obtain intermediate moisture  
68 products with improved stability over storage. This because, during OD a partial dewatering of plant  
69 tissue takes place, reducing both freezable water content and the water activity of the system (Tylewicz  
70 et al., 2011; Mauro et al., 2016). The application of OD process on strawberry tissue has been widely  
71 studied. Chang et al. (2014) studied the effect of power ultrasound and pulsed vacuum treatments on  
72 the dehydration kinetics and the status of water during osmotic dehydration of strawberries, showing  
73 that the highest water loss (lower freezable water content) and the highest decrease in firmness  
74 occurred using ultrasound treatment, while the highest solid gain and the highest firmness values were  
75 achieved by pulsed vacuum treatment. Castelló et al. (2010) observed that OD treatment promoted the

76 structural collapse, however, when calcium was added to the osmotic solution a beneficial effect on the  
77 maintenance of the sample texture was observed.

78 Since OD treatment, especially when applied at room temperature, is a time-requiring process, other  
79 pretreatments could be used before OD in order to increase the velocity of mass transfer kinetics.

80 Pulsed electric field is a process which promotes the modification of the membrane permeability by  
81 application of high voltage short time pulses (Barba et al., 2015). The application of low electric field  
82 strength creates pores in the biological membrane which affect the mass transfer in tissues. In fact,  
83 several studies of PEF-assisted OD have been carried out on different plant tissues such as apples  
84 (Dellarosa et al., 2016a; Dellarosa et al., 2016b; Amami et al., 2006), kiwifruits (Dermesonlouoglou et  
85 al., 2016; Traffano-Schiffo et al., 2016), carrots (Amami et al., 2007), potatoes (Fincan & Dejmek,  
86 2003) etc. While the effect of PEF pre-treatment on enhancing the water loss of OD treated tissues  
87 seems to be clearly and well stated, its effect on the solid gain is ambiguous. In fact, some authors  
88 reported an increase in solid uptake, for example in mango pieces (Taiwo et al., 2002) and apples  
89 (Amani et al., 2006; Dellarosa et al., 2016a), while in PEF pre-treated kiwifruit samples the solutes  
90 uptake was lower compared to untreated ones (Traffano-Schiffo et al., 2016). The impact of high-  
91 intensity electric field pulses on the mass transfer and on some physical characteristics (leaching of  
92 cell constituents, colour and texture) of strawberry halves during osmotic dehydration (OD) has been  
93 studied (Taiwo et al., 2003). Higher water loss was obtained in samples treated with a high-intensity  
94 electric field before OD. Moreover, the application of PEF before OD minimized changes in product  
95 colour and allowed to retain product compactness.

96 To the best of our knowledge, this is the first work aimed to the evaluation of the effect of PEF+OD  
97 low temperature processes on the mass transfer phenomena and water redistribution of strawberry  
98 tissue. Moreover, the changes in some quality parameters of treated strawberries from organic  
99 production were evaluated.



## 101 2. Materials and Methods

### 102 2.1. Raw material handling

103 Organic strawberries (*Fragaria+ananassa*) var “Alba” ( $10 \pm 1$  °Brix) were purchased from the local  
104 market in Cesena (Italy). The strawberries were stored at  $4 \pm 1$  °C at high relative humidity until use,  
105 for no longer than one week. Before processing, fruits were tempered at 25 °C, washed, hand stemmed  
106 and cut into rectangular shape pieces of the dimension 5 x 10 x 20 mm (height x width x length).

107

### 108 2.2. Pulsed electric field (PEF) treatment

109 Two rectangular pieces (approximately 1.3 g) were placed into a rectangular treatment chamber  
110 equipped with two stainless steel electrodes (20 x 20 mm<sup>2</sup>) with a gap between them of 30 mm and  
111 filled with 5 mL of a sodium chloride solution with the same conductivity as the strawberries (1.6  
112 mS/cm). The PEF treatments were applied to the strawberry samples at 25°C using an in-house  
113 developed pulse generator equipment based on MOSFET technology that delivers near-rectangular  
114 shape pulses.

115 PEF pre-treatments were carried out by applying a train of 100 pulses at three different pulsed electric  
116 field (E) strength (100, 200 and 400 V cm<sup>-1</sup>), a fixed pulse width of 100 µs and a repetition time of 10  
117 ms (100 Hz). The procedure setting was chosen on bases of preliminary experiments.

118

### 119 2.3. Osmotic dehydration (OD) treatment

120 The OD treatment was carried out by immersing the strawberry samples in 40 % (w/w) hypertonic  
121 solutions. Two different solutions were prepared, one with sucrose and one with trehalose dissolved in  
122 distilled water. Calcium lactate (CaLac) at a concentration of 1 % (w/w) was added to both the  
123 solutions as a structuring agent. The treatment was performed at 25 °C with continuous stirring  
124 maintaining a fruits:OD solution ratio of 1:4 (w/w) that allowed to avoid significant changes in the  
125 solution concentration during the whole treatment (data not shown).

126 The samples were analysed at different treatment times: 0, 15, 30, 60 and 120 min.

127 Both PEF and OD procedures were repeated twice for each solution.

128 All obtained samples are summarised with related abbreviations as reported in table 1.

129

130

Table 1

131

132 2.2. Analytical determinations

133 2.4.1. Mass transfer phenomena

134

135 Mass transfer phenomena during osmotic dehydration of strawberry samples was evaluated by  
 136 calculating weight reduction (WR,  $\text{kg kg}^{-1}$ ), water loss (WL,  $\text{kg kg}^{-1}$ ) and solutes gain (SG,  $\text{kg kg}^{-1}$ )  
 137 adopting the following equations:

138

$$139 \quad WR = \frac{m_t - m_0}{m_0} \quad (1)$$

$$140 \quad WL = \frac{m_t x_{wt} - m_0 x_{w0}}{m_0} \quad (2)$$

$$141 \quad SG = \frac{m_t x_{STt} - m_0 x_{ST0}}{m_0} \quad (3)$$

142 where:

143  $m_0$  - initial weight before osmotic treatment (kg)

144  $m_t$  - weight after a time t (kg)

145  $x_{w0}$  - initial water mass fraction ( $\text{kg} \cdot \text{kg}^{-1}$ )

146  $x_{wt}$  - water mass fraction after a time t ( $\text{kg} \cdot \text{kg}^{-1}$ )

147  $x_{ST0}$  - initial total solids (dry matter) mass fraction ( $\text{kg} \cdot \text{kg}^{-1}$ )

148  $x_{STt}$  - total solids (dry matter) mass fraction after a time t ( $\text{kg} \cdot \text{kg}^{-1}$ )

149 Moisture content was determined gravimetrically by drying the samples at 70°C until a constant  
150 weight was achieved (AOAC, 2002).

151

152

#### 153 2.4.2. Water distribution by TD-NMR measurements

154 In order to measure the proton transverse relaxation time ( $T_2$ ), strawberry cylinders of about 250 mg  
155 ( $h = 10 \text{ mm}$ ,  $d = 8 \text{ mm}$ ) were cut with a core borer. The samples were placed inside 10 mm outer  
156 diameter NMR tubes, in order to not exceed the active region of the radio frequency coil, and analyzed  
157 at 25 °C with the CPMG pulse sequence (Meiboom & Gill, 1958) using a ‘The Minispec’  
158 spectrometer (Bruker Corporation, Germany) operating at 20 MHz. Each measurement comprised  
159 4000 echoes over 16 scans, with an interpulse spacing of 0.3 ms and a recycle delay set at 10 s. The  
160 specified parameters, chosen to prevent sample and radio frequency coil overheat, allowed the  
161 observation of the protons with  $T_2$  higher than a few milliseconds. According to the protocol set up by  
162 Panarese et al. (2012), the CPMG decays were analyzed with the UPEN software (Borgia et al., 1998),  
163 which inverts the CPMG signal using a quasi-continuous distribution of exponential curves, and  
164 through fittings to the sum of an increasing number of exponential curves. Furthermore, a multi  
165 exponential discrete fitting was successively applied to accurately determine  $T_2$  and relative intensities  
166 of the water populations (Mauro et al., 2016). The experiment was conducted in triplicate at each  
167 treatment condition.

#### 168 2.4.3. Cell viability test by Fluorescein diacetate (FDA) staining

169 The cell viability test was performed on 1 mm-thick strawberry slices, cut with a sharp scalpel,  
170 using fluorescein diacetate (FDA, Sigma-Aldrich, USA,  $\lambda_{\text{ex}} = 495 \text{ nm}$ ,  $\lambda_{\text{em}} = 518 \text{ nm}$ ), as described by  
171 Tylewicz et al. (2013) with some modifications. Strawberry slices were incubated for 5 min in a  
172 solution containing FDA ( $10^{-4} \text{ M}$ ) and sucrose in isotonic concentration (10 %, w/w) in the darkness at  
173 room temperature. The dye used in the experiment can passively penetrate the protoplast and then it is

174 hydrolysed by cytoplasmic esterases, producing the polar product named fluorescein that only the  
175 viable cells are able to accumulate intracellularly, because it is unable to cross cellular membranes that  
176 remain intact (Mauro et al., 2016). Hence, viable cells could be easily identified by a bright  
177 fluorescence. Observations were performed under a fluorescent light in a Nikon upright microscope  
178 (Eclipse Ti-U, Nikon Co, Japan) equipped with a Nikon digital video camera (digital sight DS-Qi1Mc,  
179 Nikon Co, Japan) at a magnification of 4 ×.

180

#### 181 2.4.4. Colour

182 The colour changes of fresh, PEF pre-treated and osmodehydrated samples were investigated using a  
183 spectro-photocolorimeter mod. Colorflex (Hunterlab, USA). The measurements were made using CIE  
184  $L^*a^*b^*$  scale. The instrument was calibrated with a black and white tile ( $L^* 93.47$ ,  $a^* 0.83$ ,  $b^* 1.33$ )  
185 before the measurements. Moreover, the hue angle ( $h^\circ$ ) parameter was calculated using the following  
186 equation:

$$187 \quad h^\circ = \tan^{-1} \frac{b^*}{a^*} \quad (4)$$

188

189 where:  $a^*$  (red–green) and  $b^*$  (yellow–blue) are parameters of color measurement (Vega-Gálvez et al.,  
190 2012).

191 The analysis were conducted in twelve repetitions for randomly selected strawberry samples for each  
192 PEF pre-treatment and osmotic dehydration condition.

193

#### 194 2.4.5. Texture analysis

195 Firmness (N) was evaluated by performing a penetration test on strawberry **rectangular pieces** using a  
196 TA-HDi500 texture analyzer (Stable Micro Systems, Surrey, UK) equipped with a 5 N load cell. A  
197 stainless steel probe of 2 mm diameter was used and rate and depth of penetration were of 1 mm/s and  
198 95 %, respectively. The analysis were performed in twelve replicates.

199

## 200 2.5. Statistical Analysis

201 Significance of the PEF treatment and OD effects was evaluated by one-way analysis of variance  
202 (ANOVA, 95% significance level) and comparison of means by Duncan test at a 5% probability level  
203 using the software STATISTICA 6.0 (Statsoft Inc., Tulsa, UK).

204

## 205 3. Results and discussion

206

## 207 3.1. Mass transfer phenomena

208 The kinetics of water loss and **solid gain** during OD are shown in Figure 1 and Figure 2 **for**  
209 **sucrose and trehalose solutions, respectively**. Figure 1 shows also the effect of the different electric  
210 field strength applied on water loss and **solid** gain during osmotic dehydration of strawberries  
211 immersed in sucrose-based solution. Samples subjected to the PEF pre-treatment presented a  
212 significantly higher water loss compared to the untreated strawberry samples.

213

214

Figure 1

215

216 An improvement of water loss upon PEF pre-treatment has already **been** observed by Taiwo et  
217 al. (2003) on strawberries ( $1200 \text{ V cm}^{-1}$ ) and by Traffano-Schiffo et al. (2016) on kiwifruit (up to  $400$   
218  $\text{V cm}^{-1}$ ). The acceleration of the kinetics of water and **solids** transfer is due to the effect of  
219 permeabilization of the cell membranes induced by the PEF treatment (Amani et al., 2006; Barba et al.,  
220 2015). In the present study, the application of the lowest electric field intensity ( $100 \text{ V cm}^{-1}$ ) resulted  
221 already sufficient to increase the water loss by 12 % after one hour of osmotic dehydration. This result  
222 is in contrast with **those obtained by** Dellarosa et al. (2016), **who observed** that the treatment with  $100$   
223  $\text{V cm}^{-1}$  did not have any effect on mass transfer of apple cylinders during the OD conducted for 60

224 min. This difference could probably be explained by the different microstructure of strawberries which  
225 resulted in a different sensitivity to the electric field strength. In addition, it needs to be mentioned that,  
226 due to both the different conductivity of samples/media and the higher number of delivered pulses, the  
227 energy input applied to the strawberry samples ( $123 \text{ J kg}^{-1}$ ) was much higher compared to the one  
228 delivered to the apples ( $8 \text{ J kg}^{-1}$ ). The initial mass transfer rate in PEF treated samples was faster  
229 compared to the untreated one, proportionally to the PEF intensity. Although at the end of the osmotic  
230 treatment the samples treated at 250 and 400  $\text{V cm}^{-1}$  did not differ significantly, in agreement with  
231 Traffano-Schiffo et al. (2016). As reported by various authors (Ade-Omowaye et al., 2003;  
232 Angersbach et al., 2002; Dellarosa et al. 2016a), PEF effects can be considered time-dependent and the  
233 formation of pores and their growth in the membrane are not immediate but **continue** for several  
234 minutes after the treatment. This highlights the importance of taking into account the time elapsed  
235 from the application of pulsed electric fields before any other treatment in order to optimize PEF  
236 application in a combined multi step manufacturing process.

237 Similarly to water loss, solid gain was favoured by the application of PEF. After 120 min of OD, the  
238 **solid** gain was about 4 % in the strawberry untreated tissue, while PEF pre-treated sample reached a 5–  
239 6 % gain, in agreement with the results of Dellarosa et al. (2016a).

240 The lower enhancement of solid gain compared to the water loss has already been observed by Ade-  
241 Omowaye et al., (2003), that attributed this result to the higher molecular size of solutes compared to  
242 water and to a selective membrane permeabilization that favour dewatering rather than solute diffusion  
243 through the tissue.

244 The SG and WL behaviours of strawberry samples dehydrated in the trehalose-based solution were  
245 similar (Fig.2). However, water loss in trehalose-based solution was characterized by a higher initial  
246 rate compared to the treatment in the sucrose solution but by a lower final dehydration level. At the  
247 end of the treatment, the samples treated at 200 and 400  $\text{V cm}^{-1}$  reached the highest WL of about 50 %.

248

Figure 2

249

250

251 Interesting results were observed for **solid** gain. Up to 120 min, only the treatment with the lowest  
252 electric field strength caused a higher **solid** gain compared to the untreated sample, while the treatment  
253 at 200 and 400 V cm<sup>-1</sup> reduced the trehalose uptake due to a lower initial mass transfer rate. Generally  
254 thought, samples treated at 400 V cm<sup>-1</sup> showed a noticeably lower **solids** impregnation. Trehalose is  
255 known to exert a protective effect on cell membranes during drying or freezing (Ferrando & Spiess,  
256 2001; Atarés et al., 2008), thanks to its ability to form hydrogen bonds with the biomolecules that  
257 allows to stabilize cells and tissues preserving viability and structures (Vicente et al. 2012). In the  
258 present study, the combination of PEF with trehalose allowed to obtain a higher dewatering effect  
259 without increasing solute uptake or even reducing it.

260 **This could be considered a positive effect if you want to increase the stability of a perishable organic**  
261 **product while maintaining/considering its nutritional properties.**

262

### 263 3.2. Water redistribution upon treatments

264 Osmotic dehydration itself, generally, promotes important changes in cellular structure of different  
265 plant tissues, that can affect the water mobility and its distribution through different parts of the cellular  
266 tissue (Tylewicz et al., 2011; Panarese et al., 2012; Mauro et al., 2016). TD-NMR permitted to  
267 separately observe two main water populations located in vacuoles and cytoplasm plus extracellular  
268 spaces of strawberry tissue that corresponded to the relaxation time ( $T_2$ ) of  $1139.82 \pm 129.56$  and  
269  $251.24 \pm 23.51$ , respectively. During OD treatment it was possible to observe the decrease of the signal  
270 intensity related to the water protons located in the vacuole throughout 120 min. As a consequence, the  
271 shrinkage of vacuole led to **the increase of the intensity** of the water protons belonging to the  
272 cytoplasm and extracellular space, as shown in the way of example for the sucrose treated samples in  
273 figure 3a.

274

275

Figure 3

276

277 Results are in agreement with those reported by Cheng et al. (2014), who studied the effect of water-  
278 osmotic solute exchange on the strawberry cell compartments (vacuole, cytoplasm plus intercellular  
279 space, and cell wall) subjected to the ultrasound and vacuum assisted OD treatment in sucrose  
280 solution. The authors also observed that, upon OD treatments, the relative space occupied by the  
281 vacuole decreased while the one occupied by the cytoplasm and intercellular space increased. In other  
282 fruits such as kiwifruit (Tylewicz et al., 2011; Panarese et al., 2012) and apples (Mauro et al., 2016)  
283 similar behaviour on water distribution was observed, confirming the migration of water from the  
284 inner compartments toward the external ones.

285 Figure 3b shows the effect on water distribution due to the application of PEF on the strawberry tissue  
286 before immersion in the hypertonic solution. The electroporation induced by the treatment led to a loss  
287 of compartmentalization that is highlighted by the merging of the two proton populations into a single  
288 one. This effect was more pronounced when applied E was increased from 100 to 400 V cm<sup>-1</sup>.

289 Dellarosa et al. (2016) studied the water distribution in apple tissue subjected to PEF treatments at  
290 similar voltages and determined a no-reversibility threshold at around 150 V cm<sup>-1</sup> with 60 train pulses.  
291 In the present study even the lower voltage applied (100 V cm<sup>-1</sup>) seemed to **promote** a collapse of the  
292 cellular structures although less markedly compared to the higher voltages. As mentioned above, this  
293 discrepancy could be explained by the higher energy input applied in the present experiment and the  
294 different sensitivity of strawberry tissue to the field strength in comparison with apples.

295 Figure 3c illustrates mean T<sub>2</sub> values of the water populations throughout 120 min of the osmotic  
296 treatment. As expected, this value decreased during OD due to the water removal and the different  
297 water-solutes-biopolymers interaction. **Indeed, the water that is leaving the tissue during OD is**  
298 **characterized by high mobility, hence with long T<sub>2</sub>. Therefore, a marked decrease of T<sub>2</sub> values, from**



299  $755 \pm 60$  ms to  $478 \pm 89$  ms, for untreated strawberries was observed. Interestingly, each applied  
300 electric field strength also showed values spanning in the range 390-500 ms, immediately after PEF  
301 treatment. Such results might not be attributed to the different water content, but to the dissimilar  
302 water-solutes-biopolymers induced by the loss of compartmentalization within the strawberry tissue. In  
303 addition, similarly to control trends,  $T_2$  values continued to decline during the whole duration of the  
304 osmotic dehydration process, so when water was also removed. These results, in accordance with mass  
305 transfer data, demonstrated that OD efficiency could be highly influenced by PEF pre-treatments  
306 which eased the diffusion of inner water by markedly affecting the permeability of membranes.  
307 The samples dehydrated in trehalose-based solution (data not shown) followed a similar trend as the  
308 samples dehydrated in sucrose. Probably the marked effect of PEF contributed to hide the effect of  
309 different solutes used for dehydration.

310

### 311 3.3. Cell viability test by Fluorescein diacetate (FDA) staining

312 Figure 4 presents images of strawberry tissue after the PEF treatment followed by staining with FDA  
313 in order to investigate the possible loss of cell viability.

314 Indeed, the creation of pores in the cell membrane, through the phenomenon of electroporation, which  
315 is a function of temperature, intensity of the applied electric field, number of pulses, pulse shape, type  
316 of tissue etc. (Buckow et al., 2013), may lead to irreversible damages causing loss of cell viability.

317 In order to determine the threshold of irreversible electroporation, Dellarosa et al. (2016 b) measured  
318 the metabolic heat production and the respiration rate of apple cylinders subjected to 100, 250 and 400  
319  $V\ cm^{-1}$ . The authors found that the medium and the high applied voltages promoted a drastic loss of  
320 cell viability that was attributed to the irreversible damages of the membranes. On the other hand, the  
321 tissue treated with 100 V/cm showed metabolic indexes comparable to the fresh tissue indicating that  
322 the electroporation was only reversible and did not cause loss of cell viability. In the present  
323 experiment, although cell viability was not completely lost, strawberry samples treated with an

324 intensity of the electric field strength of  $100 \text{ V cm}^{-1}$ , showed residual cell viability, also if much lower  
325 than the fresh sample intensity, as shown in figure 4. The increase of the electric field strength induced  
326 a greater structural damage, as found in samples treated at 200 and  $400 \text{ V cm}^{-1}$  where there was a  
327 complete loss of cell viability. Consequently, cell viability was maintained even after 120 min of  
328 osmotic treatment of untreated samples (data not shown). The preservation of cell viability was  
329 observed also by Mauro et al. (2016) after 120 min in 40 % of sucrose solution. In the Mauro's study  
330 when 30% sucrose + 3 % of calcium lactate was used the cell viability was also preserved, while  
331 increasing quantity of calcium lactate up to 4% in 40% of sucrose compromised the cell viability.  
332 However, in the present study, only 1 % of calcium lactate was used, therefore this parameter was not  
333 affected by OD process, but just by PEF pre-treatment. Moreover, the PEF treated samples at  $100 \text{ V}$   
334  $\text{cm}^{-1}$  partially preserved their viability also after OD process (data not shown), while samples treated  
335 with higher E were not further investigated, due to the viability loss following PEF treatment.  
336 Therefore, with the aim of increasing the shelf-life of an organic product, characterized by quality  
337 parameters as close as possible to the fresh one, the lowest electric field strength applied in the tested  
338 range seems to be the suitable.

339

340

341

Figure 4

342

#### 343 3.4. Colour

344 Table 2 shows the  $L^*$  and hue angle ( $h^\circ$ ) values of untreated and PEF treated strawberry tissues  
345 subjected to osmotic dehydration for 120 min in both solutions.  $L^*$  parameter of untreated samples did  
346 not change during the whole OD treatment. Similar results were obtained by Nuñez-Mancilla et al.  
347 (2013) who did not notice any variation of the  $L^*$  parameter in strawberry samples subjected to the OD

348 process, while this parameter was influenced significantly by the application of high hydrostatic  
349 pressure.

350 The luminosity of the samples resulted to be affected by the electric field intensity. In fact, this  
351 parameter increased significantly after the application of PEF at the intensity of  $100 \text{ V cm}^{-1}$ , while  
352 decreased due to the application of PEF at highest field intensity. Also Wiktor et al. (2015) observed  
353 that the colour measurement showed unchanged or lower  $L^*$  value of PEF treated samples at  $E=1.85$   
354  $\text{kV cm}^{-1}$  and  $E=3$  or  $E=5 \text{ kV cm}^{-1}$ , respectively, in comparison with the untreated apple tissue. The  
355 darkening of the PEF treated samples at  $400 \text{ V cm}^{-1}$  could be related to the higher release of enzymes  
356 such as peroxidase (POD) and polyphenol oxidase (PPO) and their substrates after the electroporation  
357 of the strawberry cells membrane. In fact, Chisani et al. (2007) observed that the browning of the  
358 strawberry fruit during the storage was related to both oxidase activities. However, after 120 min of  
359 OD treatment the PEF treated samples increased their  $L^*$  values, which was significantly higher in  
360 comparison to untreated ones.

361

362

363

Table 2

364

365 Since the colour of strawberries is the mixture of red and yellow, the hue angle ( $h^\circ$ ) was also  
366 calculated and its values are reported in table 2, respectively for strawberries treated in sucrose and  
367 trehalose solution. In general OD treatment promoted a decrease of this parameter. The application of  
368 PEF promoted a further decrease of hue angle in comparison with untreated samples, which was  
369 proportional to the electric field strength applied, at least in samples dehydrated in sucrose solution.  
370 Similar results were observed by Osorio et al. (2007). The reduction of  $h^\circ$  colorimetric parameter  
371 could be due to both solubilisation of pigments in the osmotic solution and degradation of anthocyanin  
372 induced by PEF-treatment (Fathi et al., 2011; Odriozola-Serrano et al., 2008). In samples dehydrated

373 in trehalose non significant differences were observed among PEF-treated samples, if not for the  
374 samples treated by  $100 \text{ V cm}^{-1}$  at 30 min after OD that showed a significantly lower  $h^\circ$  value compared  
375 to the others. Wiktor et al. (2015) observed that the effect of PEF treatment strongly depends on the  
376 raw material properties and the treatment conditions. In fact, the authors noticed the different  
377 behaviour of carrot and apple tissue subjected to electric field strength at different intensities. In both  
378 cases browning of the tissue was observed, however in carrots it was more pronounced when the low  
379 voltage treatment was applied, while in apple with high voltage.

380

### 381 3.5. Texture

382 It is well known that OD induces plasmolysis, shrinkage of the vacuole compartment, changes in size  
383 and structure of the cell walls of outer pericarp and dissolution of the middle lamella, which could be  
384 translated in decreasing of the firmness of the plant tissue (Chiralt & Talens, 2005; Panarese et al.  
385 2012). The changes of firmness of untreated and PEF treated strawberry tissue subjected to OD  
386 treatment up to 120 min in sucrose-based solution is shown in Figure 5. OD of untreated samples  
387 promoted a decrease of strawberry firmness, already 15 min after the treatment, and increased slightly  
388 during the OD treatment. In the present experiment, PEF pre-treatment drastically reduced the  
389 hardness of strawberry samples; further, the PEF treated samples remained below the untreated ones  
390 during the whole OD process and the effect was proportional to the electric field strength applied. Also  
391 Taiwo et al. (2003) observed the decrease in firmness of strawberries halves treated with PEF ( $1200 \text{ V}$   
392  $\text{cm}^{-1}$ ;  $350 \mu\text{s}$ ) and then osmodehydrated for 4 hours in binary (sucrose, NaCl) solution. The reduction  
393 of firmness of PEF treated samples could be due to the alteration of the membrane permeability due to  
394 the pores creation and the rupture of internal structure, which promotes the softening of the tissue  
395 (Fincan & Dejmek, 2002; Wiktor et al., 2016).

396

397

Figure 5

Figure 6

398

399

400 The slight increase of the texture observed after longer OD times could be probably due to the  
401 penetration of  $\text{Ca}^{2+}$  into the strawberry tissue. The structural role of calcium ions in the cell wall is due  
402 to their interaction with pectic acid polymers to form cross-bridges that reinforce the cell adhesion,  
403 thereby reducing cell separation, which is one of the major causes of plant tissue softening (Van  
404 Buggenhout et al., 2008; Mauro et al., 2016). This increase has not been observed in the samples  
405 treated at  $400 \text{ V cm}^{-1}$ , probably because the tissue was already completely disintegrated after the PEF  
406 treatment, and did not permit the incorporation of calcium ions in the cell walls.

407 Similar results were observed in strawberries samples dehydrated in trehalose-based solution (Fig. 6).  
408 However, considering that the firmness of the material ( $0.8 \pm 0.1 \text{ N}$ ) used for the experiment was  
409 almost half compared with the value relative to the raw material used in the experiment with sucrose  
410 ( $1.35 \pm 0.2 \text{ N}$ ), the decrease of firmness following the OD process was less marked. **In fact, the**  
411 **firmness of samples dehydrated in trehalose decreased only by 36 % in comparison to 57 % of**  
412 **decrease observed in sucrose dehydrated samples already 15 min after the treatment. This behaviour**  
413 **could probably be due to the protective effect of trehalose on the tissue structure, as reported by**  
414 **Phoon et al. (2008).** The intensity of the applied electric field strength seems to be not so relevant in  
415 comparison to samples dehydrated with sucrose. Shayanfar et al. (2013) observed texture softening  
416 and loss of turgor in frozen/thawed potatoes after the PEF treatment. However, when  $\text{CaCl}_2$  and  
417 trehalose were added to the liquid medium used in PEF treatment, the samples maintained their  
418 firmness when compared to solely PEF treated samples.

419

#### 420 **4. Conclusions**

421 **PEF treatment prior to osmotic dehydration was found to positively affect the mass transfer, in term of**  
422 **water loss from the strawberry tissue. The application of the lowest electric field intensity ( $100 \text{ V cm}^{-1}$ )**  
423 **resulted already sufficient to increase the water loss by 12 % and 6%, after one hour of osmotic**

424 dehydration, respectively for strawberries dehydrated in sucrose and trehalose solution, partially  
425 preserving the cell viability and maintaining at the same time the fresh-like characteristics of fruits.

426 Concerning the solid gain results, while the solid gain was favoured by the application of all the PEF  
427 intensities in samples dehydrated in sucrose solution, the treatment at 200 and 400 V cm<sup>-1</sup> reduced the  
428 trehalose uptake due to a lower initial mass transfer rate.

429 In most of the cases, the PEF effect on different strawberry characteristics investigated was  
430 proportional to the electric field strength applied.

431 TD-NMR results showed that the diffusion of inner water was eased by PEF application because of a  
432 marked effect on membranes permeability.

433 Although similar effects on the investigated parameters were observed by using sucrose or trehalose  
434 solutions, the combination of PEF with trehalose allowed to obtain a higher dewatering effect without  
435 increasing solute uptake or even reducing it.

436 Definitely, the application of the lower field intensity and the use of trehalose for the dehydration  
437 process, seem to be the optimal combination for obtaining a semi-dried strawberry product with  
438 quality characteristics similar to the fresh one, that is a fundamental requirement for an organic  
439 production.

440

441

442

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445

446 **References**

- 447 Ade-Omowaye, B., Talens, P., Angersbach, A., & Knorr, D. (2003). Kinetics of osmotic dehydration  
448 of red bell peppers as influenced by pulsed electric field pretreatment. *Food Research International*,  
449 36(5), 475–483.
- 450 Amami, E., Fersi, A., Vorobiev, E., & Kechaou, N. (2007). Osmotic dehydration of carrot tissue  
451 enhanced by pulsed electric field, salt and centrifugal force. *Journal of Food Engineering*, 83(4), 605-  
452 613.
- 453 Amami, E., Vorobiev, E., & Kechaou, N. (2006). Modelling of mass transfer during osmotic  
454 dehydration of apple tissue pre-treated by pulsed electric field. *LWT - Food Science and Technology*,  
455 39, 1014–1021.
- 456 Angersbach, A., Heinz, V., & Knorr, D. (2002). Evaluation of process-induced dimensional changes in  
457 the membrane structure of biological cells using impedance measurement. *Biotechnology Progress*,  
458 18(3), 597–603.
- 459 AOAC International (2002). Official methods of analysis (OMA) of AOAC International (17th ed.)  
460 [USA. Method number: 920.15. Available at. <http://www.eoma.aoac.org/>].
- 461 Atarés, L., Chiralt, A., & González-Martínez, C. (2008). Effect of solute on osmotic dehydration and  
462 rehydration of vacuum impregnated apple cylinders (cv. Granny Smith). *Journal of Food*  
463 *Engineering*, 89(1), 49-56.
- 464 Badawy, M.E.I., Rabea, E.I., El-Nouby, M.A.M., Ismail, R.I.A., & Taktak, N.E.M. (2016). Strawberry  
465 Shelf Life, Composition, and Enzymes Activity in Response to Edible Chitosan Coatings.  
466 *International Journal of Fruit Science*, pp 1-20, <http://dx.doi.org/10.1080/15538362.2016.121929>, In  
467 press.
- 468 Barański, M., Średnicka-Tober, D., Volakakis, N., Seal, Ch., Sanderson, R., Stewart, G. B., Benbrook,  
469 Ch., Biavati, B., Markellou, E., Giotis, Ch., Gromadzka-Ostrowska, J., Rembiałkowska, E., Skwarło-  
470 Sońta K., Tahvonen, R., Janovská, D., Niggli, U., Nicot, P., & Leifert, C. (2014). Higher antioxidant

- 471 and lower cadmium concentrations and lower incidence of pesticide residues in organically grown  
472 crops: a systematic literature review and meta-analyses. *British Journal of Nutrition*, 112, 794–811.
- 473 Barba, F.J., Parniakov, O., Pereira, S.A., Wiktor, A., Grimi, N., Boussetta, N., Saraiva, J., Raso, J.,  
474 Martin-Belloso, O., Witrowa-Rajchert, D., Lebovka, N., & Vorobiev, E. (2015). Current applications  
475 and new opportunities for the use of pulsed electric fields in food science and industry. *Food Research*  
476 *International*, 77(4), 773–798.
- 477 Borgia, G.C., Brown, R.J.S., & Fantazzini, P. (1998). Uniform-penalty inversion of multiexponential  
478 decay data. *Journal of Magnetic Resonance*, 132(1), 65-77.
- 479 Buckow, R., Ng, S., & Toepfl, S. (2013). Pulsed electric field processing of orange juice: a review on  
480 microbial, enzymatic, nutritional, and sensory quality and stability. *Comprehensive Reviews in Food*  
481 *Science and Food Safety*, 12(5), 455-467.
- 482 Castelló, M.L., Fito, P.J., & Chiralt, A. (2010). Changes in respiration rate and physical properties of  
483 strawberries due to osmotic dehydration and storage. *Journal of Food Engineering*, 97(1), 64–71.
- 484 Cheng, X.F., Zhang, M., Adhikari, B., & Islam, M.N. (2014). Effect of Power Ultrasound and Pulsed  
485 Vacuum Treatments on the Dehydration Kinetics, Distribution, and Status of Water in Osmotically  
486 Dehydrated Strawberry: a Combined NMR and DSC Study. *Food and Bioprocess Technology*, 7(10),  
487 2782-2792.
- 488 Chiralt A., & Talens P. (2005). Physical and chemical changes induced by osmotic dehydration in  
489 plant tissues. *Journal of Food Engineering*, 67(1-2), 167–177.
- 490 Chisari, M., Barbagallo, R. N., & Spagna, G. (2007). Characterization of Polyphenol Oxidase and  
491 Peroxidase and Influence on Browning of Cold Stored Strawberry. *J. Agric. Food Chem.*, 55,  
492 3469–3476.
- 493 Dellarosa, N., Ragni, L., Laghi, L., Tylewicz, U., Rocculi, P., & Dalla Rosa, M. (2016a). Time  
494 domain nuclear magnetic resonance to monitor mass transfer mechanisms in apple tissue promoted by



- 495 osmotic dehydration combined with pulsed electric fields. *Innovative Food Science & Emerging*  
496 *Technologies*, 37, Part C, 345-351.
- 497 Dellarosa, N., Tappi, S., Ragni, L., Laghi, L., Rocculi, P., & Dalla Rosa, M. (2016b). Metabolic  
498 response of fresh-cut apples induced by pulsed electric fields. *Innovative Food Science and*  
499 *Technologies*, <http://dx.doi.org/10.1016/j.ifset.2016.06.016>. In press.
- 500 Dermesonlouoglou, E., Zachariou, I., Andreou, V., & Taoukis, P.S. (2016). Effect of pulsed electric  
501 fields on mass transfer and quality of osmotically dehydrated kiwifruit. *Food and Bioproducts*  
502 *Processing*, 100, Part B, 535-544.
- 503 Fathi, M., Mohebbi, M., & Razavi, A.M.S. (2011). Application of image analysis and artificial neural  
504 network to predict mass transfer kinetics and color changes of osmotically dehydrated kiwifruit. *Food*  
505 *Bioprocess Technology*, 4(8), 1357–1366.
- 506 Ferrando, M., & Spiess, W.E.L. (2001). Cellular response of plant tissue during the osmotic treatment  
507 with sucrose, maltose, and trehalose solutions. *Journal of Food Engineering*, 49(2), 115-127.
- 508 Fincan, M., & Dejmek P. (2003). Effect of osmotic pretreatment and pulsed electric field on the  
509 viscoelastic properties of potato tissue. *Journal of Food Engineering*, 59(2–3), 169-175.
- 510 Gamboa-Santos, J., Montilla, A., Soria, A.C., Cárcel, J.A., García-Pérez, J.V., & Villamiel, M. (2014).  
511 Impact of power ultrasound on chemical and physicochemical quality indicators of strawberries dried  
512 by convection. *Food Chemistry*, 161, 40–46.
- 513 Kadivec, M., Tijssens, L.M.M., Kopjar, M., Simčič, M., & Požrl, T. (2016). Modelling the Colour of  
514 Strawberry Spread During Storage, Including Effects of Technical Variations. *Polish Journal of Food*  
515 *and Nutrition Sciences*, 66(4), 271–276.
- 516 Mauro, M.A, Dellarosa, N, Tylewicz, U., Tappi, S., Laghi, L, Rocculi, P. & Dalla Rosa, M. (2016).  
517 Calcium and ascorbic acid affect cellular structure and water mobility in apple tissue during osmotic  
518 dehydration in sucrose solutions. *Food Chemistry*, 195, 19-28.

- 519 Meiboom, S., & Gill, D. (1958). Modified spin-echo method for measuring nuclear relaxation times.  
520 *Review of Scientific Instruments*, 29(8), 688–691.
- 521 Nuñez-Mancilla, Y., Pérez-Won, M., Uribe, E., Vega-Gálvez, A. & Di Scala, K. (2013). Osmotic  
522 dehydration under high hydrostatic pressure: Effects on antioxidant activity, total phenolics  
523 compounds, vitamin C and colour of strawberry (*Fragaria vesca*). *LWT - Food Science and Technology*  
524 *52*, 151-156.
- 525 Odriozola-Serrano, I., Soliva-Fortuny, R., & Martín-Belloso, O. (2008). Phenolic acids, flavonoids,  
526 vitamin C and antioxidant capacity of strawberry juices processed by high-intensity pulsed electric  
527 fields or heat treatments. *European Food Research and Technology*, 228, 239-248.
- 528 Osorio, C., Franco, M.S., Castano, M.P., Gonzalez-Miret, M.L., Heredia, J.F., & Morales, L.A (2007).  
529 Colour and flavor changes during osmotic dehydration of fruit. *Innovative Food Science and Emerging*  
530 *Technologies*, 8, 353-359.
- 531 Panarese, V., Laghi, L., Pisi, A., Tylewicz, U., Dalla Rosa, M., & Rocculi, P. (2012). Effect of osmotic  
532 dehydration on *Actinidia deliciosa* kiwifruit: A combined NMR and ultrastructural study. *Food*  
533 *Chemistry*, 132, 1706–1712.
- 534 Peleg, M. (1988). An empirical model for the description of moisture sorption curves. *Journal of Food*  
535 *Science*, 53, 1216–1217.
- 536 Phoon, P. Y., Galindo, F. G., Vicente, A., Dejmek, P. (2008). Pulsed electric field in combination with  
537 vacuum impregnation with trehalose improves the freezing tolerance of spinach leaves. *Journal of*  
538 *Food Engineering*, 88(1), 144–148.
- 539 Shayanfar, S., Chauhan, O. P., Toepfl, S., & Heinz, V. (2013). The interaction of pulsed electric fields  
540 and texturizing — antifreezing agents in quality retention of defrosted potato strips. *International*  
541 *Journal of Food Science & Technology*, 48(6), 1289–1295.

- 542 Taiwo, K.A., Eshtiaghi, M.N., Ade-Omowaye, B.I.O., & Knorr, D. (2003). Osmotic dehydration of  
543 strawberry halves: influence of osmotic agents and pretreatment methods on mass transfer and product  
544 characteristics. *International Journal of Food Science and Technology*, 38, 693–707.
- 545 Taiwo, K.A., Angersbach A., & Knorr D. (2002). Influence of high intensity electric field pulses and  
546 osmotic dehydration on the rehydration characteristics of apple slices at different temperatures.  
547 *Journal of Food Engineering*, 52(2), 185-192.
- 548 Traffano-Schiffo, M.V., Tylewicz U., Castro-Giraldez, M., Fito P.J. , Ragni L., & Dalla Rosa M.  
549 (2016). Effect of pulsed electric fields pre-treatment on mass transport during the osmotic dehydration  
550 of organic kiwifruit. *Innovative Food Science & Emerging Technologies*, 38, Part A, 243–251.
- 551 Tylewicz, U., Panarese, V., Laghi, L., Rocculi, P., Nowacka, M., Placucci, G., & Dalla Rosa, M.  
552 (2011). NMR and DSC Water Study during Osmotic Dehydration of *Actinidia deliciosa* and *A.*  
553 *chinensis* kiwifruit. *Food Biophysics*, 6(2), 327-333.
- 554 Tylewicz, U., Romani, S., Widell, S., & Gómez Galindo, F. (2013). Induction of Vesicle Formation by  
555 Exposing Apple Tissue to Vacuum Impregnation. *Food and Bioprocess Technology*, 6(4), 1099-1104.
- 556 Van Buggenhout, S., Grauwet, T., Van Loey, A., & Hendrickx, M. (2008). Use of  
557 pectinmethylesterase and calcium in osmotic dehydration and osmodehydrofreezing of strawberries.  
558 *European Food Research and Technology*, 226, 1145–1154.
- 559 Vega-Gálvez, A., Ah-Hen, K., Chacana, M., Vergana, J., Martínez-Monzó, J., García-Segovia, P.,  
560 Lemus-Mondaca, R., & Di Scala, K. (2012). Effect of temperature and air velocity on drying kinetics,  
561 antioxidant capacity, total phenolic content, colour, texture and microstructure of apple (var. Granny  
562 Smith) slices. *Food Chemistry*, 132(1), 51-59.
- 563 Velickova, E., Winkelhausen, E., Kuzmanova, S., Alves, V.D., & Moldão-Martins, M. (2013). Impact  
564 of chitosan-beeswax edible coatings on the quality of fresh strawberries (*Fragaria ananassa cv*  
565 *Camarosa*) under commercial storage conditions. *LWT - Food Science and Technology*, 52, 80-92.

- 566 Vicente, S., Nieto, A. B., Hodara, K., Castro, M. A., & Alzamora, S. M. (2012). Changes in structure,  
567 rheology, and water mobility of apple tissue induced by osmotic dehydration with glucose or  
568 trehalose. *Food and Bioprocess Technology*, 5(8), 3075-3089.
- 569 Wiktor, A., Gondek, E., Jakubczyk, E., Nowacka, M., Dadan, M., Fijalkowska, A., & Witrowa-  
570 Rajchert, D. (2016). Acoustic emission as a tool to assess the changes induced by pulsed electric field  
571 in apple tissue. *Innovative Food Science and Emerging Technologies*, 37, 375–383.
- 572 Wiktor, A., Sledz, M., Nowacka, M., Rybak, K., Chudoba, T., Lojkowski, W., & Witrowa-Rajchert, D.  
573 (2015). The impact of pulsed electric field treatment on selected bioactive compound content and color  
574 of plant tissue. *Innovative Food Science and Emerging Technologies*, 30, 69–78.

1 **Figure Captions**

2 **Figure 1.** Solid gain and water loss of untreated and PEF pre-treated strawberry samples, as a function  
3 of the osmotic dehydration time in sucrose-based solution.

4 The same letter on the same column means no significant difference between the samples by the Duncan test ( $p < 0.05$ ).

5 **Figure 2.** Solid gain and water loss of untreated and PEF pre-treated strawberry samples, as a function  
6 of the osmotic dehydration time in trehalose-based solution.

7 The same letter on the same column means no significant difference between the samples by the Duncan test ( $p < 0.05$ ).

8 **Figure 3.**  $T_2$  -weighted signal distribution, normalized to unitary area, of OD samples with sucrose (a)  
9 and sample immediately after PEF pre-treatments (b). Mean transverse relaxation time ( $T_2$ ) values  $\pm$   
10 standard deviation PEF pre-treated and control strawberries during 120 min from immersion into the  
11 sucrose solution (c).

12 **Figure 4.** Microscopy images of fresh strawberry tissue and after the PEF treatment followed by  
13 staining with FDA.

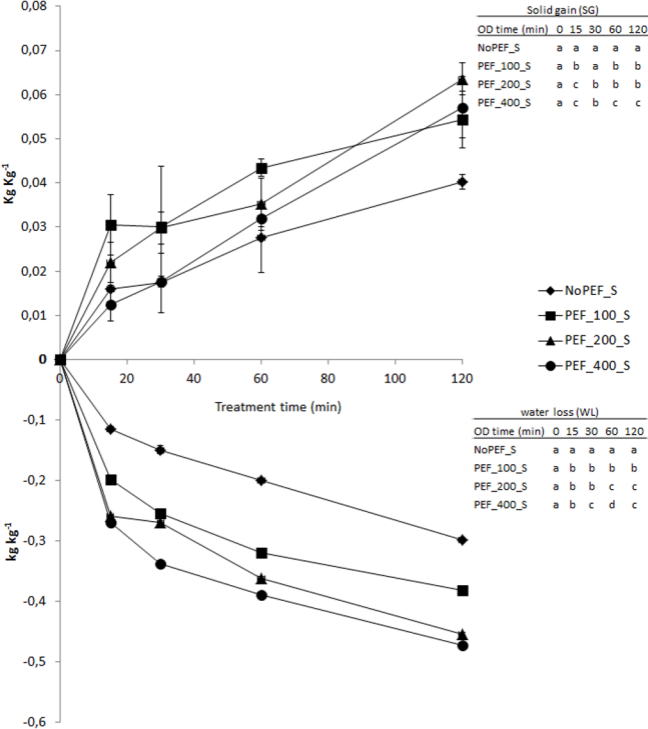
14 **Figure 5.** Firmness (N) of untreated and PEF pre-treated strawberry samples, as a function of the  
15 osmotic dehydration time in sucrose-based solution.

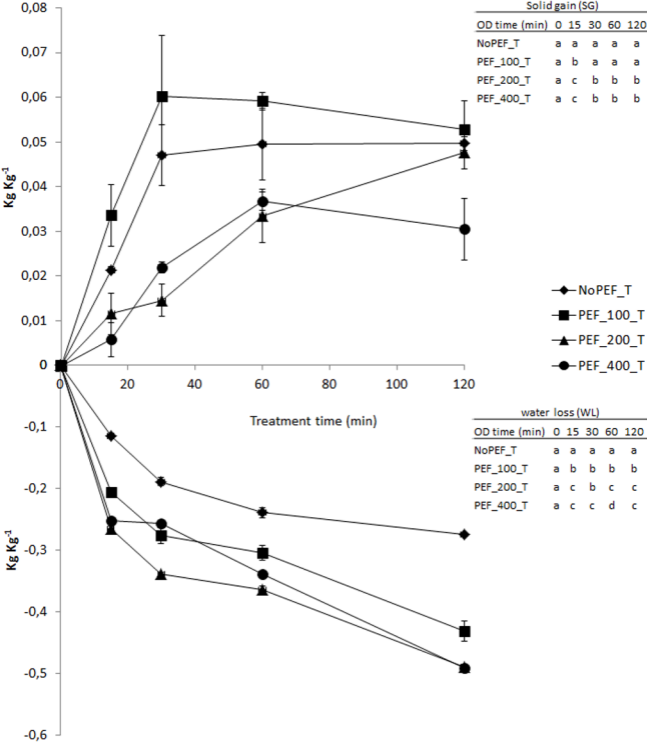
16 The same letter on the same column means no significant difference between the samples by the Duncan test ( $p < 0.05$ ).

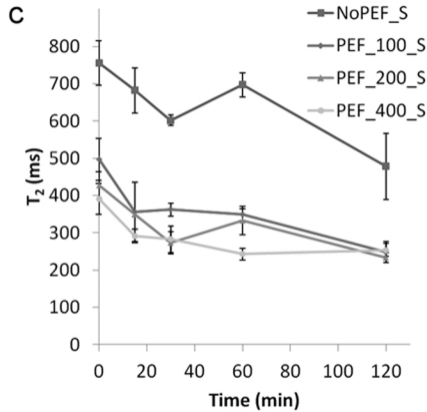
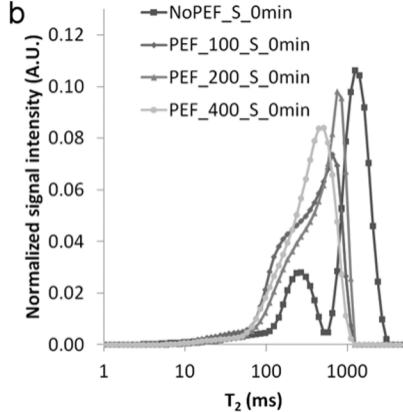
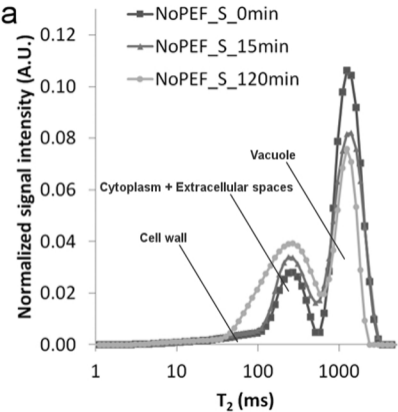
17 **Figure 6.** Firmness (N) of untreated and PEF pre-treated strawberry samples, as a function of the  
18 osmotic dehydration time in trehalose-based solution.

19 The same letter on the same column means no significant difference between the samples by the Duncan test ( $p < 0.05$ ).

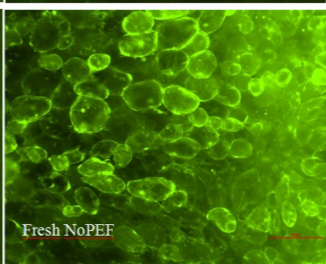
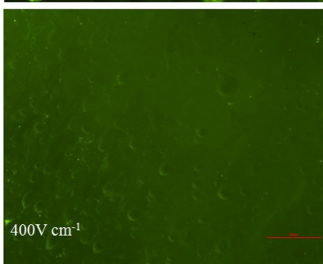
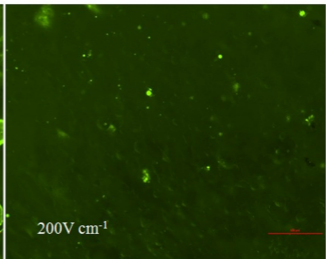
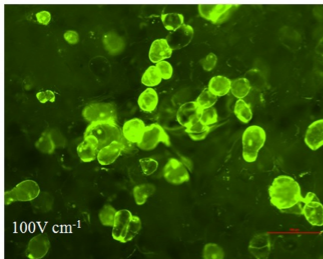
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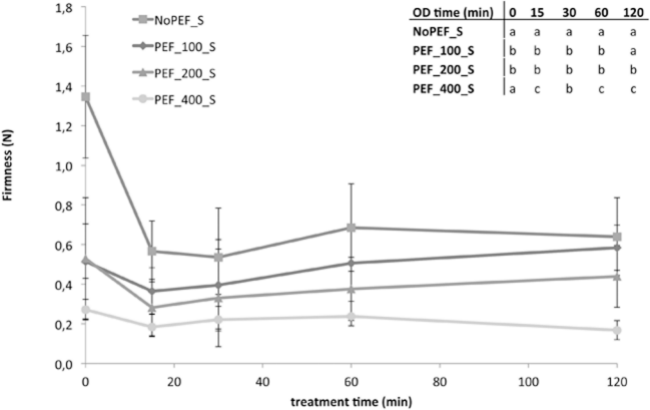












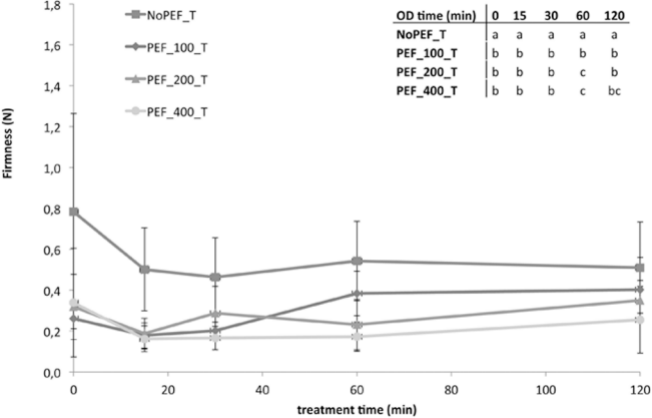


Table 1. Codification of analysed samples

Sample code	Electric field (V cm <sup>-1</sup> )	Type of solution
NoPEF_S	0	Sucrose
PEF_100_S	100	Sucrose
PEF_200_S	200	Sucrose
PEF_400_S	400	Sucrose
NoPEF_T	0	Trehalose
PEF_100_T	100	Trehalose
PEF_200_T	200	Trehalose
PEF_400_T	400	Trehalose

Table 2. Colour parameters ( $L^*$  - Lightness,  $h^\circ$  - hue angle) of untreated and PEF pre-treated strawberry samples, as a function of the osmotic dehydration time in both sucrose and trehalose solutions.

OD Time	0 min	15 min	30 min	60 min	120 min
	$L^*$				
NoPEF_S	$35 \pm 4^b$	$32 \pm 6^b$	$40 \pm 6^a$	$38 \pm 3^{bc}$	$37 \pm 4^{de}$
PEF_100_S	$42 \pm 4^a$	$38 \pm 5^{ab}$	$38 \pm 3^{ab}$	$42 \pm 3^a$	$45 \pm 5^a$
PEF_200_S	$35 \pm 1^b$	$35 \pm 2^b$	$34 \pm 2^{bc}$	$39 \pm 2^{ab}$	$42 \pm 2^{ab}$
PEF_400_S	$26 \pm 2^c$	$42 \pm 2^a$	$34 \pm 2^{bc}$	$35 \pm 2^{cd}$	$41 \pm 2^{abc}$
NoPEF_T	$35 \pm 4^b$	$37 \pm 6^{ab}$	$36 \pm 5^{abc}$	$37 \pm 5^{bc}$	$34 \pm 5^e$
PEF_100_T	$41 \pm 4^a$	$35 \pm 6^{ab}$	$33 \pm 2^c$	$35 \pm 3^{cd}$	$35 \pm 4^{ce}$
PEF_200_T	$28 \pm 3^c$	$30 \pm 1^c$	$34 \pm 2^{bc}$	$33 \pm 2^d$	$39 \pm 3^{cd}$
PEF_400_T	$27 \pm 2^c$	$37 \pm 4^{ab}$	$33 \pm 3^c$	$35 \pm 3^{cd}$	$38 \pm 2^{cde}$
	$h^\circ$				
NoPEF_S	$40 \pm 2^a$	$36 \pm 4^a$	$36 \pm 2^a$	$35 \pm 1^a$	$35 \pm 2^a$
PEF_100_S	$35 \pm 2^c$	$29.9 \pm 0.9^b$	$29 \pm 2^{cd}$	$29 \pm 2^b$	$29 \pm 2^c$
PEF_200_S	$38 \pm 2^{ab}$	$29 \pm 1^b$	$31 \pm 2^{bc}$	$28 \pm 1^b$	$25 \pm 3^{de}$
PEF_400_S	$35 \pm 4^{bc}$	$24 \pm 1^c$	$27 \pm 3^{de}$	$24 \pm 1^c$	$23 \pm 2^e$
NoPEF_T	$40 \pm 1^a$	$37 \pm 2^a$	$38 \pm 1^a$	$33 \pm 1^a$	$32.1 \pm 0.7^b$
PEF_100_T	$35 \pm 2^{bc}$	$30 \pm 2^b$	$24 \pm 2^e$	$24 \pm 5^{bc}$	$26 \pm 2^d$
PEF_200_T	$34 \pm 3^d$	$28 \pm 1^b$	$27 \pm 1^d$	$25.5 \pm 0.8^c$	$23 \pm 2^e$
PEF_400_T	$36 \pm 2^{bc}$	$28 \pm 2^b$	$32 \pm 3^b$	$28 \pm 1^b$	$24 \pm 2^e$

The same letter on the same column means no significant difference by the Duncan test ( $p < 0.05$ ).