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Modelling the recovery of biocompounds from peach waste assisted by pulsed electric fields or thermal treatment

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Abstract: The recovery of non-purified bioactive extracts (70% ethanol) from peach pomace (PP) was assisted by conventional thermal treatment (CTT, 50 °C up to 90 min) or pulsed electric fields (PEF, specific energy input, EV, of 0.0014–2.88 kJ/kg). The maximum concentration of biocompounds and antioxidant activity, assessed with spectrophotometric and HPLC methods, was obtained upon 40 min by CTT and 0.0014 kJ/kg by PEF, which took 16 μ s. A two-step mechanism was proposed when CTT was applied, considering a first step (zero-order kinetic) in which the PP biocompounds were released into the extraction media and a second degradation stage (first-order). A significant relationship was found between EV and PP biocompound degradation during PEF extraction, and a two-term degradation model was proposed to explain obtained data. The CTT or PEF-assisted recovery of biocompounds from PP was adequately explained by the proposed kinetic models, which are feasible tools to understand the involved phenomena in the extraction procedures.

Subject: Submission of original manuscript

Dear Editor,

Attached you can find the file containing a manuscript entitled *Modelling the recovery of biocompounds from peach waste assisted by pulsed electric fields or thermal treatment* submitted by Stella Plazzotta, Raquel Ibarz, Lara Manzocco and Olga Martín-Belloso to **Journal of Food Engineering** after revision. All the authors have read and approved the manuscript.

The application of advanced manufacturing technologies to assist the extraction processes from fruit residues have received increasing attention in recent years to reduce wastes in such a way that extracts with an improved content of bioactive compounds and great physico-chemical properties could be obtained. For this end, in this study, we have explored the use of thermal or pulsed electric field processes to assist the recovery of bioactive extracts, working with frozen and air-dried peach juice wastes and try to explain the involved phenomena from a mechanistic point of view through kinetic models. Different parameters were studied to allow tracking of the extraction process, such as the content of polyphenols, flavonoids, anthocyanins and vitamin C as well as the antioxidant activity of the frozen and air-dried peach extracts, together with the time required for the biocompounds recovery. In addition, the most advantageous assisted extraction technology for peach waste valorization was identified, regarding the extraction efficacy.

The authors believe that the current research article may significantly contribute to shed light on the valorization of food wastes, understanding the phenomena involved in the thermal and nonthermal assisted extraction by kinetic models.

This scientific contribution was selected to be submitted to a JOURNAL OF FOOD ENGINEERING special issue "Role of Food Engineering in Sustainability" from the XII edition of CIBIA, Iberoamerican Congress of Food Engineering - 2019.

I hope that this article could satisfy the requirements of Journal of Food Engineering, so that you might consider it for publication in the Journal.

Please do not hesitate to contact me for any further eventuality.

I am looking forward to hearing from your earliest news.

Yours sincerely,

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1 **Modelling the recovery of biocompounds from peach waste assisted by pulsed electric fields or**
2 **thermal treatment**

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7

8 **Abstract**

9 The recovery of non-purified bioactive extracts (70% ethanol) from peach pomace (PP) was assisted by
10 conventional thermal treatment (CTT, 50 °C up to 90 min) or pulsed electric fields (PEF, specific energy input,
11 E_V , of 0.0014–2.88 kJ/kg). The maximum concentration of biocompounds and antioxidant activity, assessed with
12 spectrophotometric and HPLC methods, was obtained upon 40 min by CTT and 0.0014 kJ/kg by PEF, which
13 took 16 μ s. A two-step mechanism was proposed when CTT was applied, considering a first step (zero-order
14 kinetic) in which the PP biocompounds were released into the extraction media and a second degradation stage
15 (first-order). A significant relationship was found between E_V and PP biocompound degradation during PEF
16 extraction, and a two-term degradation model was proposed to explain obtained data.

17 The CTT or PEF-assisted recovery of biocompounds from PP was adequately explained by the proposed kinetic
18 models, which are feasible tools to understand the involved phenomena in the extraction procedures.

19 **Keywords:** Peach waste; Kinetic models; Temperature; Pulsed electric fields

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21

22 1. Introduction

23 European Union (EU) fruit juice and nectars consumption was 9.2 billion litres in 2017, with peach (*Prunus*
24 *persica L.*) representing the fourth flavour profile in the market (AIJN, 2018). During peach juice production, a
25 huge amount of waste is generated. Usually, peach pomace (PP), referring to the pressing solid residue generated
26 from peach juicing process, accounts for approximately 10% of the initial fruit weight (Argun & Dao, 2017).
27 Peach is rich in antioxidant biocompounds that are mainly localized in the pulp and peel tissues, which are the
28 main constituents of PP. In particular, phenolic compounds have been found to be the major contributor to the
29 antioxidant activity of peach, followed by ascorbic acid and carotenoids (Gil, Tomás-Barberán, Hess-Pierce, &
30 Kader, 2002; Redondo, Arias, Oria, & Venturini, 2017; Redondo, Venturini, Luengo, Raso, & Arias, 2018).
31 Although this, like other vegetable by-products, PP is currently discarded in landfills, anaerobically digested or
32 composted. These PP management options not only represent a wastage of valuable biomass, but also an
33 environmental burden and an economic cost for companies. For these reasons, the identification of alternative
34 management options, able to properly valorise PP, are required in order to turn this industrial discard into an
35 added-value product. In this regard, the extraction of biocompounds could represent an effective valorisation
36 strategy of PP (El Darra et al., 2018).

37 Traditional techniques employed in the extraction of antioxidant compounds from fruits involve the use of
38 organic solvents and high temperatures (Li, Smith, & Hossain, 2006). Such extraction processes present high
39 costs and environmental impact, and often result in the thermo-degradation of biocompounds. Moreover, the
40 extraction may be negligible if the cells are intact. In fact, the extraction of biocompounds from vegetable tissues
41 is a mass transfer process, whose rate principally depends on the resistance of the biocompound to migrating into
42 the extraction solvent. The compartmentalization of biocompounds into the cells of the vegetable tissue and their
43 interaction with the vegetable matrix increase this resistance to extraction (Donsì, Ferrari, & Pataro, 2010).
44 Therefore, assisting-technologies, able to disrupt cellular tissue integrity have been increasingly proposed to
45 enhance extraction efficiency, while preserving the bioactive compounds in the extract. Such strategies include
46 the use of microwaves, high pressures (pressurized liquids, supercritical fluids, high pressure homogenization),
47 ultrasounds, and pulsed electric fields (PEF) (Rombaut, Tixier, Bily, & Chemat, 2014). In the case of PEF, the

48 vegetable material is subjected to external electric fields (1–10 kV/cm) for a short time (microseconds), resulting
49 in the so-called “electroporation” of the cell membranes, which leads to an increase in the cell membrane
50 permeability, thus favouring the biocompounds extraction (Donsì et al., 2010). The application of PEF has many
51 advantages over other assisting techniques. As compared to pressure-based technologies, PEF process has lower
52 energy costs and does not cause the release of undesirable substances into the extraction solvent, due to the slight
53 denaturation of the cell membranes (Redondo et al., 2018). Moreover, as compared to microwaves and
54 ultrasounds, the loss of thermosensitive bioactive compounds is reduced because no temperature increase is
55 generated (Cacace & Mazza, 2003). Based on these technological advantages, PEF has already been used to
56 extract marketable compounds from different vegetable matrices (Kumari, Tiwari, Hossain, Brunton, & Rai,
57 2018).

58 It must be noted that the high moisture content of PP is one of the main issues related to its management, since it
59 makes it quickly prone to microbial spoilage (Ajila, Brar, Verma, & Prasada Rao, 2012). Therefore, in a realistic
60 scenario, it is likely that PP should be preliminary frozen or air-dried in order to be subsequently subjected to
61 any extraction process, possibly modifying the content, composition and extractability of bioactive compounds.

62 Based on these considerations, the aim of this study was to evaluate the recovery of non-purified biocompounds
63 in extracts from PP by extraction processes assisted by PEF or conventional thermal treatment (CTT) and
64 explain the involved phenomena through kinetic models. Frozen and dried PP were subjected to PEF or CTT
65 assisted extractions using a 70% hydroalcoholic solvent and the obtained extracts were analysed for
66 biocompound concentration and antioxidant activity. Moreover, the extraction efficacy was evaluated to identify
67 the more advantageous assisted extraction technology for PP valorization.

68 **2. Materials and Methods**

69 **2.1 Reagents**

70 The used reagents were absolute ethanol (Scharlau, Barcelona, Spain.), bidistilled water (Milli-Q system,
71 Millipore, Bedford, USA), Fast Blue reagent (Sigma Aldrich, St.Louis, U.S.A.), Sodium carbonate (Carlo Erba,
72 Milan, Italy) gallic acid 97% (Sigma Aldrich, St. Louis, U.S.A.), Sodium acetate anhydrous (Sigma Aldrich, St.

73 Louis, U.S.A.), Aluminum chloride (Sigma Aldrich, St. Louis, U.S.A.), Quercetin: 2-(3,4-Dihydroxyphenyl)-
74 3,5,7-trihydroxy-4H-1-benzopyran-4-one (Sigma Aldrich, St. Louis, U.S.A.), 1,4-dithiothreitol (DTT) (Sigma
75 Aldrich, St. Louis, U.S.A.), Potassium chloride (Sigma Aldrich, St. Louis, U.S.A.), Meta-phosphoric acid
76 (Sigma Aldrich, St. Louis, U.S.A.), DPPH: 2,2-Diphenyl-1-picrylhydrazyl (Sigma Aldrich, St. Louis, U.S.A.),
77 Trolox: (±)-6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid 97% (Sigma Aldrich, St. Louis, U.S.A.).

78 **2.2 Peach pomace (PP)**

79 The peach pomace (PP), residue from peach juice extraction, either frozen (-18 °C) or dried (140 °C) and ground
80 was kindly furnished by Indulleida S.A. (Alguaire, Lleida, Spain). Frozen and dried PPs were characterized by a
81 moisture content of about 85.0 ± 1.1 and 4.0 ± 1.0 (g/100 g), respectively, determined using the official
82 gravimetric method (AOAC, 1997). Frozen PP was thawed at 4 °C prior to use. Both frozen and dried PPs were
83 used at room temperature (20 °C).

84 **2.3 Preparation of PP extracts**

85 PP extracts were prepared using aqueous ethanol (70:30 EtOH:H₂O w/w) as solvent. PP (20 g) was placed into a
86 glass flask and added with 200 mL of solvent. The suspension was homogenized by manual mixing for 1 min
87 and immediately subjected to the different extraction protocols. The dispersions were then filtered using 1.2 µm
88 filters (Sartorius 17593-100 cellulose acetate 25 mm/1.20 µm, Filtros, Anovia, Spain) to remove the solid residue,
89 obtaining the extracts. The latter were stored in the dark at -18 °C until analysis. Control extracts were prepared
90 by filtering the PP dispersions immediately after the manual mixing, without any further assisted extraction.

91 **2.3.1 Conventional thermal treatment (CTT)**

92 PP dispersions were subjected to conventional thermal treatment (CTT) by using a thermal bath set at 50 °C.
93 Sample temperature reached 50 °C in less than 5 min and temperature was monitored in order to maintain it at
94 50 °C during the extraction, that was carried out up to 90 min. Sample temperature was measured during CTT by
95 a copper-constantan thermocouple probe connected to a portable data logger (mod. TP100, XS Instruments,
96 Carpi, Italy).

97 **2.3.2 Pulsed electric field treatment (PEF)**

98 PEF treatments were carried out using a unit with 0.1 μF capacitor with an exponential decaying waveform
99 (Physics International, San Leandro, CA, USA). The chamber consists in two parallel stainless-steel plates where
100 the electric field is created when the electric energy is discharged. PP dispersions were placed in the chamber
101 and were treated at 0.8-10 kV/cm, using 4-30 monopolar pulses of 4 μs , at a frequency of 0.1 Hz, which
102 corresponded to a specific energy input (E_v) up to 72 kJ/kg, calculated according to equation 1 (Bot et al., 2018):

$$103 \quad E_v = \frac{V^2 t}{R m} \quad (\text{Equation 1})$$

104 where V is the voltage (V), t is the time (s) calculated as pulse duration (4 μs) multiplied by pulse number, R is
105 the electrical resistance (Ω) and m (kg) is the PP mass.

106 **2.4 Determination of bioactive compound concentration**

107 **2.4.1 Total polyphenolic (TPC)**

108 Total phenolic content (TPC) was determined using the Fast Blue method (Medina, 2011), adapted to a 96-well
109 microplate. A portion of 200 μL of ethanolic extract, properly diluted, was mixed with 20 μL of Fast Blue
110 reagent (1 mg/mL) and 20 μL of Na_2CO_3 solution (0.05 g/mL). Samples were mixed and stored at room
111 temperature in darkness for 90 min. Absorbance was measured at 420 nm using a UV/VIS Thermo Multiskan
112 Spectrum spectrophotometer (Thermo Scientific, Waltham, USA). Ethanol blanks (70%, w/w) were run in each
113 assay. Calibration curve was built with gallic acid (0–500 mg/L). Results were expressed as mg of gallic acid
114 equivalents (GAE) per 100 g of dry matter (dm).

115 **2.4.2 Total flavonoid (TF)**

116 Total flavonoids (TF) were evaluated using the method of Humadi and Istudor (2008), adapted to a 96-well
117 microplate. An amount of 25 μL of the ethanolic extract was added with 140 μL of deionized water, 10 μL of
118 $\text{C}_2\text{H}_3\text{NaO}_2$ (1 g/L) and 10 μL of AlCl_3 (0.1 g/mL). The mixture was homogenized and stored in the dark for 40
119 min. The absorbance was determined at 405 nm using a UV/VIS Thermo Multiskan Spectrum
120 spectrophotometer (Thermo Scientific, Waltham, USA). Blanks containing water instead of $\text{C}_2\text{H}_3\text{NaO}_2$ and AlCl_3

121 were run in each assay. Calibration curve was built with quercetin (0–1000 mg/L). Results were expressed as mg
122 of quercetin equivalents (QE) per 100 g of dry matter (dm).

123 **2.4.3 Total anthocyanin (TA)**

124 Total anthocyanin (TA) content was evaluated by differential pH method (Chaovanalikit & Wrolstad, 2004). A
125 portion of 2.5 mL of extract was added to 2.5 mL of 45 g/L metaphosphoric acid solution containing 1,4-
126 Dithiothreitol (7.2 g/L). An aliquot of the sample (1 mL) was added with 1 mL of pH 1.0 buffer (0.025 M
127 potassium chloride). Similarly, 1 mL of the sample was added with 1 mL of pH 4.5 buffer (0.4 g/L sodium
128 acetate). Absorbance (A) was measured using a CECIL 2021 spectrophotometer (Cecil Instruments Ltd.,
129 Cambridge, UK) at 520 and 700 nm. Absorbance was calculated as reported in equation 2:

$$130 \quad A = [(A_{520} - A_{700})_{pH1.0}] - [(A_{520} - A_{700})_{pH4.5}] \quad (\text{Equation 2})$$

131 The total anthocyanin content (TA)(mg/L) was calculated using equation 3:

$$132 \quad TA = \frac{A \times W \times DF \times 1000}{\epsilon \times L} \quad (\text{Equation 3})$$

133 Where ϵ is the cyanindin-3-glucoside molar absorption coefficient (26,900), L is the cell path length (1
134 cm), W is the molecular weight of cyanindin-3-glucoside (449.2 Da), DF is the dilution factor. Data
135 were expressed as mg of cyanindin-3-glucoside equivalents (CGE) per 100 g of dry matter (dm).

136 **2.4.4 Vitamin C (VIT C)**

137 The extraction of vitamin C (VIT C) was based on the procedure proposed by Odriozola-Serrano, Hernández-
138 Jover and Martín-Belloso (2007). A portion of 2.5 mL of extract was added to 2.5 mL of 45 g/L metaphosphoric
139 solution containing 1,4-Dithiothreitol (7.2 g/L). The mixture was homogenized, passed through a Millipore 0.45
140 μm membrane and injected in the HPLC system. The HPLC system was equipped with a 600 Controller and a
141 486 Absorbance Detector (Waters, Milford, MA) working at 245 nm. Samples were introduced onto the column
142 through a manual injector equipped with a sample loop (20 μl). The flow rate was fixed at 1.0 mL/min at room
143 temperature. A reverse-phase C18 Spherisorb® ODS2 (5 μm) stainless steel column (4.6 mm 250 mm) was used

144 as stationary phase. The mobile phase was a 0.1 g/L solution of sulphuric acid adjusted to pH 2.6 (Sanchez-Mata
145 et al., 2000). Calibration curve was built with L-ascorbic acid (0-50 mg/L). Results were expressed as mg of VIT
146 C per 100 g of dry matter (dm).

147 **2.5 Determination of antioxidant activity (AA)**

148 DPPH assay was used to assess the free radical scavenging activity. The assay was performed according to
149 Redondo et al. (2018) adapted to a microplate reader. The reaction was initiated by addition of 280 µL/well
150 DPPH solution in ethanol (25 µg/mL) to 20 µL/well extracts, properly diluted. The reaction mixture was kept in
151 the dark for 10 min and its absorbance was then measured at 517 nm using a UV/VIS Thermo Multiskan
152 Spectrum spectrophotometer (Thermo Scientific, Waltham, USA). Ethanol blanks (70 g/100 g) were run in each
153 assay. The antioxidant activity (AA) was evaluated by measuring the variation in absorbance at 515 nm after 15
154 min of reaction. Calibration curve was built with trolox (0.005–0.250 mg/L). Results were expressed as mmol of
155 trolox equivalents (TE) per 100 g of dry matter (dm).

156 **2.6 Extraction efficacy**

157 The extraction efficacy was calculated according to equation 4:

$$158 \text{ Efficacy (\%)} = \frac{C_{max} - C_{control}}{C_{control}} \times 100 \quad (\text{Equation 4})$$

159 where C_{max} represents the maximal concentration or maximal antioxidant activity reached by PEF or CTT
160 assisted extractions for PP extracts, and $C_{control}$ is the extract control concentration or antioxidant activity
161 obtained from untreated PP extracts. ANOVA test (section 2.8) was used to identify the maximum concentration
162 or antioxidant activity.

163 **2.7 Kinetic models**

164 **2.7.1 Extraction kinetic considerations**

165 The content variation of the different biocompounds extracted by applying CTT processes was evaluated through
166 a kinetic mechanism consisting of two consecutive and simultaneous stages. The proposed mechanism considers
167 a first step in which the bioactive compounds (B) are released from the substrate (S) and pass from the food
168 matrix to the solution according to a zero kinetic order, and a second step, in which the bioactive compounds

169 may disappear from the solution, leading to degraded derivatives of bioactive compounds (B_D), following a first
170 kinetic order (eq. 5):



172 For CTT, the first and second stage of the extraction mechanism have been reported to have a kinetic constant k_0
173 and an order $n = 0$ and a kinetic constant k_1 and an order $n = 1$, respectively (Ibarz, Pagán, & Garza, 1999). Thus,
174 the variation of the concentration of each bioactive or the extract antioxidant activity (C) as a function of
175 extraction time (t) may be derived from equation 6:

$$176 \quad \frac{d C_B}{d t} = k_0 - k_1 C_B \quad (\text{Equation 6})$$

177 This differential equation can be integrated with the initial condition that, for $t = 0$, the concentration of the
178 bioactive compound is C_{B0} . This integration allows obtaining equation 7:

$$179 \quad C_B = K - (K - C_{B0}) \cdot e^{-k_1 t} \quad (\text{Equation 7})$$

180 where C_B is the concentration of bioactive compounds or the antioxidant activity of the extract at time t during
181 thermal extraction, C_{B0} is the initial concentration ($t = 0$) and K is a constant relation between k_0 and k_1 ($K = \frac{k_0}{k_1}$).

182 **2.7.2 Influence of applied energy density**

183 When food matrices are treated for extraction purposes by assisted technologies, commonly, some of the
184 extractable biocompounds are degraded depending on the effect of the treatment variable (time, temperature,
185 energy density, etc.). This treatment variable is the one that during the process exerts the role of independent
186 variable, while the concentration of the component that undergoes degradation is the dependent variable. In
187 many processes, the dependent variable (y) varies decreasing according to a degradation function starting from
188 the initial value of the dependent variable (y_0), until reaching an equilibrium value (y_{eq}).

189 In order to obtain a model for those processes, we consider an exponential decrease variation, according to
190 equation 8:

$$191 \quad y = y_{eq} + (y_0 - y_{eq}) \cdot e^{-k'_i x} \quad (\text{Equation 8})$$

192 In the case of PP extracts obtained by PEF the dependent variable C_B represents the concentration of different
193 biocompounds, C_{eq} is the equilibrium value, C_{B0} is the initial value, k'_i is the kinetic constant or constants of the

194 degradation process and the energy density (E_v) is the independent variable, defined as reported in eq. 1. In the
195 PEF extraction processes, an overshoot was observed at low E_v values, allowing biocompound release into the
196 extraction media. By contrast, with the increase of E_v , a progressive decrease of biocompound concentration was
197 observed. It is assumed that the biocompounds extracted from PP can be divided in at least two categories,
198 showing different sensitivity to the PEF treatment conditions, so that a two-term exponential decay model was
199 proposed, which explains the biocompound degradation in our study (equation 9):

$$200 \quad C_B = C_{eq} + (C_{B0} - C_{eq}) \cdot (e^{-k'_1 E_v} + e^{-k'_2 E_v}) \quad (\text{Equation 9})$$

201 where k'_1 and k'_2 are the degradation kinetic constants of the biocompounds with different sensitivities to the
202 applied E_v .

203 **2.8 Statistical analysis**

204 All determinations were expressed as the mean \pm standard error of at least three repeated measurements from
205 two experiment replicates. Statistical analysis was performed by using R v. 3.0.2 (The R Foundation for
206 Statistical Computing). Bartlett's test was used to check the homogeneity of variance, one-way ANOVA was
207 carried out and the Tukey test was used to determine statistically significant differences among means ($p < 0.05$).
208 Experimental data were fitted to the kinetic expressions by non-linear regression procedures using
209 TableCurve2D software (Jandel Scientific, ver. 5.01). The fittings were calculated at a 95% significance level
210 and the goodness of fit was evaluated based on statistical parameters of fitting (R^2).

211 **3. Results and Discussion**

212 **3.1 Characterization of frozen and dried PP**

213 In this study, extracts rich in antioxidant biocompounds were obtained from frozen and dried PP. Freezing or
214 drying would be required in a realistic PP valorisation scenario to stabilize fresh PP and allow its further
215 processing.

216 Control extracts were obtained from frozen and dried PP and their biocompound composition and antioxidant
217 activity is reported in Table 1. Interestingly, the total phenolic content (TPC) of the extracts from dried PP (416
218 ± 7 mg GAE/100 g dm) resulted significantly higher ($p < 0.05$) than that of the frozen one (204 ± 4 mg GAE/100

219 g dm) (Table 1). These results are most likely attributable to the matrix drying treatment. The latter, in fact, not
220 only increases the porosity, and thus the extractive surface, of the vegetable matrix (Londoño-Londoño et al.,
221 2010), but is also responsible for the formation of thermal-induced novel compounds. In particular, dried PP
222 extracts may include Maillard reaction derivatives, able to react with the Folin reagent used for TPC
223 determination (Echavarria, Pagán, & Ibarz, 2013; Mrkic, Cocci, Dalla Rosa, & Sacchetti, 2006). By contrast,
224 total flavonoids (TF) resulted higher ($p < 0.05$) in the frozen PP extract (32 ± 3 mg QE/100 g dm) than in the dried
225 PP (12.1 ± 0.8 mg QE/100 g dm) (Table 1). This can be due to flavonoid degradation during peach pomace air-
226 drying, which has been observed in different vegetables (Sharma et al., 2015; Zainol, Abdul-Hamid, Bakar, &
227 Dek, 2009). Moreover, anthocyanins (TA), and vitamin C (VIT C) content of the frozen PP extract were $0.30 \pm$
228 0.04 mg CGE/100 g dm and 61 ± 5 mg VIT C/100 g dm, respectively, while they were not detectable in the
229 dried PP extracts. This is surely attributable to the fact that the high temperature applied (140 °C) to produce PP
230 flour degraded these compounds. In this regard, Kara and Ercçelebi (2013) found a 90% anthocyanin reduction in
231 mulberry juice upon thermal treatment at 80 °C. Similarly, Vikram, Ramesh, and Prapulla (2005) reported a 50%
232 VIT C degradation in orange juice upon only 3 min heating at 90 °C. These compounds are known to exert a
233 prominent antioxidant activity (AA) and their almost complete absence in the dried PP extract strongly affected
234 its AA (97 ± 9 mg TE/100 g dm), which resulted significantly lower ($p < 0.05$) than that of the frozen PP extract
235 (131.0 ± 0.3 mg TE/100 g dm, Table 1).

236 **3.2 Extraction assisted by conventional thermal treatment (CTT)**

237 The treatment temperature for CTT assisted extraction was set at 50 °C, which is commonly indicated as the
238 minimum temperature for thermal processes (Patras, Brunton, O'Donnell, & Tiwari, 2010), in order to preserve
239 as much as possible bioactive compounds from thermal damage. The maximum biocompound concentration and
240 antioxidant activity (C_{max}) obtained upon the CTT extraction procedure was identified based on ANOVA.
241 According this analysis, the extract from frozen PP presented C_{max} values for TPC, TF, TA and AA of 400 ± 21
242 mg GAE/100 g dm, 147 ± 3 mg QE/100 g dm, 2.74 ± 0.09 mg CGE/100 g dm and 185 ± 2 mg TE/100 g dm,
243 respectively, which resulted about 2.0, 4.7, 9.1 and 1.4 times higher than those of the corresponding control
244 extract (Table 1). By contrast, the C_{max} value relevant to VIT C (61 ± 5 mg/100 g dm) resulted comparable to

245 that of the control extract ($p \geq 0.05$, Table 1). In the case of CTT of dried PP extracts, the C_{max} values for TPC
246 (524 ± 27 mg GAE/100 g dm), TF (108 ± 1 mg QE/100 g dm) and AA (143 ± 7 mg TE/100 g dm) resulted 1.2,
247 8.9 and 1.5 times higher than those of control extracts (Table 1), respectively, while TA and VIT C were always
248 not detectable.

249 Figure 1 reports the evolution of biocompound concentration and antioxidant activity during CTT. For both
250 frozen and dried PP, the biocompound concentration and the AA of the extracts increased with the extraction
251 time up to a certain time, after which, a subsequent decrease in the extraction rate, until reaching a plateau value,
252 was observed. As already anticipated, the only exception was represented by VIT C, whose extraction was not
253 promoted by CTT extraction, probably due to the thermal sensitivity of this biocompound (Rawson et al., 2011).
254 This extraction pattern largely agrees with literature studies relevant to the extraction in hydroalcoholic solutions
255 (50-80% ethanol) of bioactive compounds from vegetable by-products including grape seeds and soybeans
256 (Bucić-Kojić, Planinić, Tomas, Bilić, & Velić, 2007; Jokic et al., 2010). Similar results were observed by El
257 Darra et al. (2018) in PP (pressed skins and pulp residues obtained by peach processing into jams and purees)
258 subjected to ethanolic solid-liquid extraction at 50 °C.

259 The two-stage mechanism proposed in equation 5 fit well the obtained data in the CTT assisted extraction of
260 biocompounds and their antioxidant activity, as it is shown in Figure 1. In the first extraction stage, the solvent
261 diffuses inside the cellular structure and biocompounds are extracted from the matrix, increasing their
262 concentration in the extraction solvent; in the second one, an almost stabilization of the extraction yield is
263 reached, which means that biocompound disappearance from the extract occurs concomitantly to extraction,
264 possibly due to biocompound thermal degradation (Ibarz et al., 1999).

265 CTT extraction data were modelled using the kinetic model presented in eq. 7, which well-fitted experimental
266 data, with a R_{adj}^2 higher than 0.90 (Table 2). The estimated parameters showed a value of K always higher than 1,
267 indicating a predominance of extraction step (associated to the kinetic constant k_0) over thermal degradation (k_1).
268 The latter seemed to occur similarly for all the biocompounds, as indicated by comparable k_1 values. By contrast,
269 differences in extraction rates (k_0) were observed. In fact, in the case of frozen PP, TPC and TF showed k_0 (16
270 and 6 c.u./min) and consequently K values (507 ± 22 and 174 ± 9 c.u.) two order of magnitude higher than those

271 of TA ($k_0 = 0.084$ c.u./min; $K = 3.6 \pm 0.5$ c.u.) (Table 2), suggesting that TA were extracted according to a
272 slower kinetics. Although the similar kinetic values observed in frozen and dried PP for both TPC and TF, the k_0
273 and k_1 of AA resulted two-folds higher in the case of frozen PP ($k_0 = 10$ c.u./min; $k_1 = 0.054 \pm 0.012$ min⁻¹),
274 indicating that both stages occurred more rapidly. This possibly suggests that the biocompounds extracted from
275 frozen PP exerted a higher antioxidant activity as compared to those extracted from dried PP but were also more
276 prone to degradation.

277 3.3 Extraction assisted by pulsed electric fields (PEF)

278 Frozen and dried PP extracts were obtained applying PEF at field strengths from 0.8 up to 10 kV/cm and for
279 increasing pulse numbers up to 30, leading to energy values up to 20 and 70 kJ/kg, for frozen and dried PP,
280 respectively. As expected, PEF treatments did not induce significant increase in sample temperature, which
281 remained lower than 22 °C. Extraction data showing TPC, TF, TA, VIT C and AA as a function of the applied
282 energy density are reported in Figure 2.

283 As compared to the control extract (Table 1), the biocompound content and the AA of frozen and dried PP
284 extracts were significantly enhanced ($p < 0.05$) by PEF extraction at the lowest energy densities (E_v) values, i.e. in
285 the range 0.02-0.07 and 0.06-0.26 kJ/kg for, respectively (Figure 2). These E_v values were in fact associated to
286 the maximum concentration of the considered biocompounds and antioxidant activity (C_{max}). These results can
287 be explained based on the capacity of PEF to electroporate the PP vegetable tissue, leading to a faster
288 solubilization of compounds in the extraction solvent (Donsì et al., 2010). By contrast, an increase in PEF E_v
289 beyond these threshold values led to extracts with progressively lower biocompound concentration and AA, until
290 reaching a plateau value (Figure 2). For example, the application of an E_v of 0.02 kJ/kg to the frozen PP resulted
291 in TPC, TF, TA, VIT C and AA values about 1.6, 5.1, 11.8, 1.8 and 1.1 times higher than those of the
292 corresponding control extract (Table 1), while an increase of E_v up to 70 kJ/kg resulted in extraction values
293 comparable or even lower than those of the control extract. The degradation of both anthocyanins and vitamin C
294 has been reported to increase with the increase of PEF treatment intensity in previous studies. Odriozola-
295 Serrano, Soliva-Fortuny, Gimeno-Añó, and Martín-Belloso (2008) noticed a significant decrease in VIT C
296 content of tomato juice with the increase of both PEF treatment time and electric field strength. Similar results

297 were also observed by Zhang et al. (2007) on the degradation of cyanidin-3-glucoside in a model system. By
298 contrast, it must be noted that these results were not expected in the case of other phenolic compounds (TPC and
299 TF), since most of literature studies relevant to PEF extraction of bioactive compounds from waste materials
300 found that PEF extractive efficacy progressively increases with the overall PEF energy, due to the progressive
301 tissue disintegration, (Donsi et al., 2010; Knorr & Angersbach, 1998; Kumari et al., 2018). This difference with
302 the literature suggests that, in the present study, the TPC and TF biocompounds of the PP were more sensitive to
303 PEF degradation. To our knowledge, no data are available on the effect of PEF on an already strongly damaged
304 tissue. In most studies aiming at extracting biocompounds from vegetable discards, the waste material is freshly
305 prepared in laboratory conditions, or freeze-dried, which would guarantee a low cellular damage. By contrast, in
306 the present work, the considered waste material was either frozen or air-dried and ground to flour. It can be
307 inferred that these waste treatments altered the stability of biocompounds by changing their
308 compartmentalization in the cellular tissue. Freezing and drying, in fact, strongly damage cells, favouring the
309 release of intracellular compounds, possibly making them more sensitive to PEF conditions (Karam, Petit,
310 Zimmer, Djantou, & Scher, 2016; Xu, Li, Wang, Yu, & Shao, 2017). This hypothesis is supported by literature
311 studies showing that the increase in PEF-induced bioactive release is commonly associated to a more
312 pronounced degradation of the extracted biocompounds upon further storage (Leong, Burritt, & Oey, 2016).
313 Based on these considerations, the extraction model reported in section 2.7.2 was proposed. According to this
314 mechanism, the degradation of biocompounds upon PEF treatments beyond a threshold E_v value, can be
315 modelled using the two-terms degradation model described by equation 9, which adequately fitted experimental
316 data, as indicated by the high R^2 (Table 3).

317 The proposed degradation model assumes that the PP biocompounds can be classified into two major classes,
318 showing different sensitivity to degradation. In particular, the more labile compounds are identified by the
319 degradation constant k'_1 (ranged from 0.22 to 9.2 kg/kJ), which resulted much higher than that of the second
320 class of biocompounds, which are the more resistant and are identified by the constant k'_2 (ranged from 0.001 to
321 0.012 kg/kJ) (Table 3). It can be noted that the k'_2 values obtained in frozen and dried PP resulted comparable;
322 by contrast, k'_1 values resulted higher for frozen matrix, indicating a more rapid degradation kinetic. During

323 solid-liquid extraction, three stages take place: (i) solute phase change, during which the biocompounds pass
324 from the solid phase to the liquid, where they are dissolved through the solid-liquid interface; (ii) diffusion of the
325 solute in the solvent contained in the pores of the solid: the solute is transferred from inside the solid particle to
326 its surface, due to the concentration gradient between the solid-liquid interface and the outer surface of the solid,
327 according to Fick law; (iii) transfer of the solute from the surface of the particles to the surface of the solution,
328 driven by a concentration gradient. Differently from dried PP, where it is likely that all the 3 stages took place,
329 the extraction from frozen PP is thought to occur mainly based on the second and third stage, since the matrix
330 was already hydrated, possibly making the first stage more rapid.

331 **3.4 CTT and PEF extraction efficacy**

332 The C_{max} values identified by ANOVA (see section 3.2) were used to calculate the CTT and PEF extraction
333 efficacy according to equation 4 (Table 4). A CTT of at least 40-50 min was needed for reaching the C_{max} in both
334 frozen and dried PP and, beyond this time, no further significant increase was observed. The TF extraction
335 efficacy was 367 ± 11 and 790 ± 12 for frozen and dried PP, respectively, which resulted much higher as
336 compared to the extraction efficacy relevant to TPC (frozen: 96 ± 10 ; dried: 26 ± 7) and AA (frozen: 41.1 ± 1.3 ;
337 dried: 48 ± 6) in both matrices. The extraction efficacy of TA from frozen PP resulted particularly high ($809 \pm$
338 30) while VIT C was not effectively extracted by CTT, giving an extraction efficacy of 0.25 ± 0.03 .

339 Regarding PEF extraction efficacy, the minimum E_V was identified as the condition allowing the C_{max}
340 (corresponding to the C_{B0} from Table 3) to be obtained, which were used to estimate the extraction efficacy
341 (Table 4). In the case of dried PP, although PEF treatments resulted in extracts presenting TPC and AA values
342 not significantly different from those of control extract ($p \geq 0.05$), as indicated by the extraction efficacies (-7 ± 5
343 and -17 ± 8 , respectively), they were quite effective in the extraction of TF (extraction efficacy of 621 ± 51). In
344 the case of frozen PP, PEF resulted in a good extraction efficacy of TPC (57.3 ± 0.4), TF (409 ± 47), VIT C (77
345 ± 3), AA (14 ± 5), but especially of TA (1080 ± 110).

346 As compared to CTT extraction efficacy, PEF treatments resulted more efficient ($p < 0.05$) in the extraction of
347 TF, TA and VIT C from frozen PP. In addition, it must be underlined that PEF treatments allowed obtaining C_{max}
348 extraction efficacy higher than those of CTT in a much shorter time. In this sense, the minimum E_V intensity was

349 delivered by 4-pulse treatments, corresponding to 16 μ s of actual treatment. In this regard, PEF treatments have
350 been largely shown to present a higher efficiency as compared to traditional extraction (Donsi et al., 2010). In
351 this sense, PEF treatments have been successfully applied for the valorisation of vegetable waste streams into
352 extracts presenting a commercial interest, such as pigments, antioxidants, and flavours. For example, PEF
353 treatments at 1-5 kV/cm have been applied to tomato juice waste leading to an extraction efficacy around 45% of
354 β -carotene (Andreou, Dimopoulos, Dermesonlouoglou, & Taoukis, 2020; Pataro, Carullo, & Ferrari, 2019).
355 Similarly, Peiró, Luengo, Segovia, Raso, and Almajano (2019), and Frontuto et al. (2019) found that PEF
356 treatments at field strength lower than 10 kV/cm enhance polyphenol extraction from lemon residues and potato
357 peels by 300% and 10%, respectively.

358 **4. Conclusions**

359 The results obtained in this study allow concluding that the recovery of biocompounds from peach pomace,
360 assisted by conventional thermal treatment (CTT) or pulsed electric fields (PEF) can be adequately explained by
361 the proposed kinetic models, which result to be feasible tools to understand the involved phenomena and predict
362 the assisted extraction results.

363 Process requirements should be accurately evaluated in order to select the more advantageous extraction
364 procedure. In this regard, although drying would allow reducing waste volumes and avoiding cold-chain storage,
365 freezing better preserves the biocompounds originally present in the peach pomace. Additionally, it must be
366 underlined that PEF treatments would require extraction times in the order of μ s, which is much shorter than the
367 time required for thermal extraction (40 min), reaching similar extraction efficiencies. Thus, in the optic of
368 developing an industrial process for peach waste valorisation, PEF would allow a significant reduction in
369 extraction time. Hence, PEF technology needs E_V between 0.02 and 0.06 kJ/kg to reach maximum biocompound
370 extraction from peach pomace. Nevertheless, the process should be properly optimized in order to avoid a fast
371 degradation of the extracted biocompounds. In particular, it seems that the characteristics of the vegetable matrix
372 before extraction play a key-role in determining PEF extraction efficacy.

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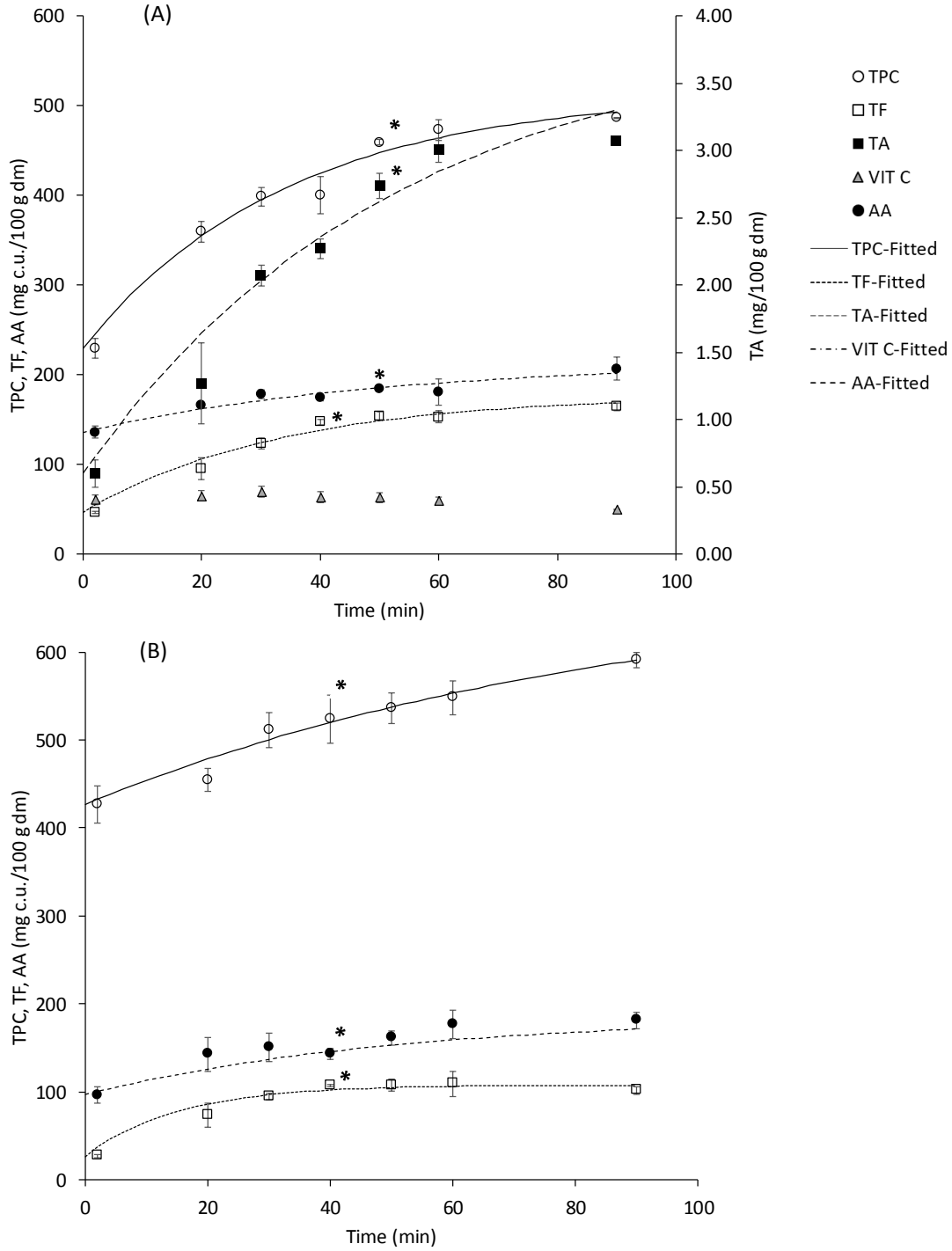
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Highlights

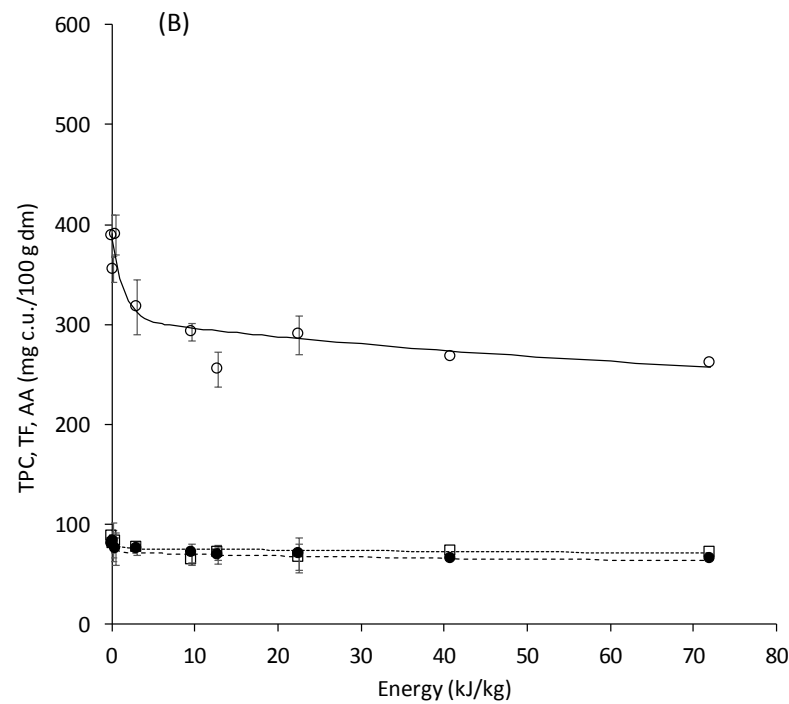
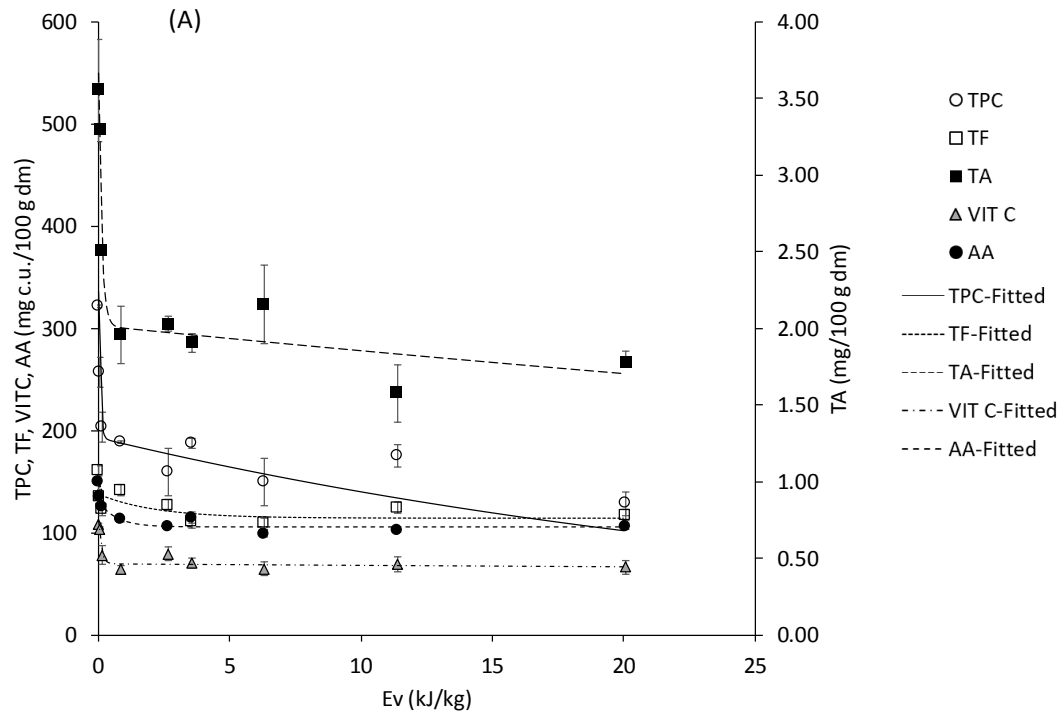
- PEF treatment resulted more efficient in the assisted extraction of TF, TA and VIT C
- Proposed kinetic models were proved to explain the thermal and PEF assisted extraction
- Extraction was predominant over degradation steps in the CTT assisted extraction
- A significant relationship was found between PEF E_v and biocompound degradation



1

2 Figure 1. Evolution of antioxidant biocompounds concentration assisted by CTT extraction process for frozen
 3 (A) and dried (B) peach waste. Data shown are a mean \pm standard deviation. TPC: Total phenolic content (mg
 4 GAE/100 g dm); TF: Total flavonoid content (mg QE/100 g dm); TA: Total anthocyanin content (mg CGE/100
 5 g dm); AA: Antioxidant scavenging activity (mg TE/100 g dm) measured by DPPH assay; c.u.: concentration
 6 units; * maximal concentration (C_{max}) identified by ANOVA.

Figure 2



1

2 Figure 2. Evolution of antioxidant biocompounds concentration assisted by PEF extraction process for frozen
 3 (A) and dried (B) peach pomace. Data shown are a mean \pm standard deviation. TPC: Total phenolic content (mg
 4 GAE/100 g dm); TF: Total flavonoid content (mg QE/100 g dm); TA: Total anthocyanin content (mg CGE/100
 5 g dm); Vit C: Total vitamin C content; AA: Antioxidant scavenging activity (mg TE/100 g dm) measured by
 6 DPPH assay; c.u.: concentration units.

1 Table 1. Biocompound concentration and antioxidant activity of control extracts obtained from untreated frozen
 2 and dried peach pomace. Data shown are a mean \pm standard deviation. TPC: Total phenolic content (mg
 3 GAE/100 g dm); TF: Total flavonoid content (mg QE/100 g dm); TA: Total anthocyanin content (mg CGE/100
 4 g dm); VIT C: Vitamin C (mg VIT C/100 g dm); AA: Antioxidant scavenging activity (mg TE/100 g dm)
 5 measured by DPPH assay; ND: not detectable.

<i>Peach pomace</i>	<i>TPC</i>	<i>TF</i>	<i>TA</i>	<i>VIT C</i>	<i>AA</i>
Frozen	204 \pm 4	32 \pm 3	0.30 \pm 0.04	61 \pm 5	131.0 \pm 0.3
Dried	416 \pm 7	12.1 \pm 0.8	ND	ND	97 \pm 9

6

7

8 Table 2. Estimated kinetic parameters of CTT (equation 7) to describe the assisted extraction process for frozen
 9 and dried peach pomace. Data shown are a mean \pm standard error. TPC: Total phenolic content (mg GAE/100 g
 10 dm); TF: Total flavonoid content (mg QE/100 g dm); TA: Total anthocyanin content (mg CGE/100 g dm); AA:
 11 Antioxidant scavenging activity (mg TE/100 g dm) measured by DPPH assay; c.u.: concentration units.

12 CTT model: $C_B = K - (K - C_{B0}) \cdot e^{-k_1 t}$

<i>Peach pomace</i>	<i>Biocompound/ Antioxidant activity</i>	C_{B0} (c.u.)	K (c.u.)	k_1 (min^{-1})	k_0 (c.u./min)*	R^2
Frozen	TPC	212 \pm 18	507 \pm 22	0.032 \pm 0.007	16	0.9797
	TF	35 \pm 8	174 \pm 9	0.034 \pm 0.007	6.0	0.981
	TA	0.35 \pm 0.24	3.6 \pm 0.5	0.023 \pm 0.008	0.084	0.9631
	AA	130 \pm 5	186 \pm 3	0.054 \pm 0.012	10.0	0.9692
Dried	TPC	411 \pm 17	574 \pm 28	0.027 \pm 0.011	15	0.9360
	TF	15 \pm 8	110 \pm 5	0.059 \pm 0.014	6.5	0.9695
	AA	94 \pm 10	189 \pm 17	0.027 \pm 0.012	5.2	0.9290

13 * calculated as $K \times k_1$

14

15 Table 3. Estimated kinetic parameters of PEF (equation 9) to describe the assisted extraction process for frozen
 16 and dried peach pomace. Data shown are a mean \pm standard error. TPC: Total phenolic content (mg GAE/100 g
 17 dm); TF: Total flavonoid content (mg QE/100 g dm); TA: Total anthocyanin content (mg CGE/100 g dm); VIT
 18 C: Vitamin C (mg/100 g dm); AA: Antioxidant scavenging activity (mg TE/100 g dm) measured by DPPH
 19 assay; c.u.: concentration units.

20

$$\text{PEF model: } C_B = C_{eq} + (C_{B0} - C_{eq}) \cdot (e^{-k_1' E_V} + e^{-k_2' E_V})$$

<i>Peach waste</i>	<i>Biocompound/ Antioxidant activity</i>	C_{B0} (c.u.)	C_{eq} (c.u.)	k_1' (kg/kJ)	k_2' (kg/kJ)	R^2
Frozen	TPC	371 \pm 32	182 \pm 10	15 \pm 4	0.012 \pm 0.006	0.9516
	TF	176 \pm 17	117 \pm 6	17 \pm 9	0.0010 \pm 0.0095	0.8603
	TA	3.9 \pm 0.3	2.01 \pm 0.13	8.2 \pm 3.0	0.008 \pm 0.007	0.9422
	VIT C	119 \pm 11	70 \pm 5	9.2 \pm 4.5	0.003 \pm 0.009	0.8788
	AA	156 \pm 8	109 \pm 3	8.5 \pm 3.4	0.007 \pm 0.008	0.9300
Dried	TPC	386 \pm 13	278 \pm 18	0.31 \pm 0.19	0.002 \pm 0.004	0.9221
	TF	86 \pm 3	68 \pm 5	0.31 \pm 0.29	0.0010 \pm 0.0061	0.7616
	AA	80 \pm 2	70 \pm 3	0.22 \pm 0.19	0.008 \pm 0.008	0.9156

21

22 Table 4. Extraction efficacy of the conventional thermal treatment (CTT) and pulsed electric fields (PEF)
 23 assisted extraction process for frozen and dried peach pomace. Data shown are a mean \pm standard error. TPC:
 24 Total phenolic content (mg GAE/100 g dm); TF: Total flavonoid content (mg QE/100 g dm); TA: Total
 25 anthocyanin content (mg CGE/100 g dm); VIT C: Vitamin C (mg/100 g dm); AA: Antioxidant scavenging
 26 activity (mg TE/100 g dm) measured by DPPH assay.

<i>Peach pomace</i>	<i>Biocompound/ Antioxidant activity</i>	<i>Extraction efficacy (%)</i>	
		<i>CTT</i>	<i>PEF</i>
Frozen	TPC	96 \pm 10	57.3 \pm 0.4
	TF	367 \pm 11	409 \pm 47
	TA	809 \pm 30	1080 \pm 110
	VIT C	0.25 \pm 0.03	77 \pm 3
	AA	41.1 \pm 1.3	14 \pm 5
Dried	TPC	26 \pm 7	-7 \pm 5
	TF	790 \pm 12	621 \pm 51
	AA	48 \pm 6	-17 \pm 8

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: