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Kiwifruit waste valorisation through innovative snack development

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Abstract

Currently, in the case of kiwifruits, those fruit with the weight lower than 65 g are considered waste. The production of dried snacks with high nutritional functionality could be a valid alternative to use the kiwifruit waste, with positive economic impact on the entire production chain. Therefore, the aim of this work was to evaluate the effect of pulsed electric field - PEF (200 V/cm) and/or osmotic dehydration - OD (trehalose at 40%) pre-drying treatments on drying kinetics at 50, 60, and 70°C, and on colour and nutritional properties (vitamin C and antioxidant compounds) of 'Jintao' (yellow-fleshed) kiwifruit snacks. At every temperature, the PEF treated snacks showed the highest drying rate. Moreover, PEF treatment appeared to be a valid innovative alternative for the production of fruit snacks with high nutritional quality. A better retention of Vitamin C and antioxidant compounds was obtained in dried yellow kiwifruit subjected to PEF treatment.

Keywords: *Actinidia chinensis*, pulsed electric field, osmotic dehydration, hot-air drying

INTRODUCTION

Kiwifruits (*Actinidia spp.*) that are undersized (< 65g) and that do not meet the requirements in accordance with Commission Regulation (EC) No 1673/2004 are considered not adequate for sale and distribution, therefore are considered waste. In general, undersized kiwifruits are utilized in industrial food processing for the production of fruit juices and/or for biorefineries. Kiwifruit production generates large quantities of waste and by-products, including peels, seeds and pruning residues. Hence, an important challenge for food industries is to manage this waste and, when possible, its valorisation (Galanakis et al., 2016). The production of dried snacks with high nutritional functionality could be a valid alternative for the valorisation of waste kiwifruits, with a positive economic impact on the entire production chain. Kiwifruit are a good source of bioactive compounds (i.e., vitamin C, polyphenols) that contribute to their high antioxidant capacity (Ma et al., 2017). Besides the high nutritional value of this type of fruit, it has to be considered that food processing steps could damage the biological tissues and consequently change the functionality of the nutritional components, for example inducing oxidative reactions (Aguilera et al., 2003). The production of fruit snacks usually requires the use of high drying temperatures (> 60 °C), with a high energy consumption and which may negatively affect the overall quality of the product (i.e., sensory, nutritional and functional attributes). Among conventional drying methods, hot-air drying (Tylewicz et al., 2019) and osmotic dehydration (Luchese et al., 2015) are commonly used in post-harvest production. However, these drying techniques are usually time and energy demanding, resulting in the production of poor quality dried fruits (Onwude, et al., 2016). Innovative technologies can be applied as pre-drying treatments in combination with conventional ones, for the production of dried snacks. The innovation could, in this way,

be useful in reducing the drying times, the drying temperature and, therefore, lead to the production of high-quality food products by means of a sustainable process approach.

Among the innovative technologies, pulsed electric fields (PEF) is gaining a lot of attention as a treatment applied before the drying process. The modification of cell membrane permeability that PEF causes could increase the velocity of mass transfers and, thus, affect the drying kinetics. Moreover, PEF treatment can be combined with osmotic dehydration (OD) for the modulation of specific plant structural features, for example, the retention of colour and inhibition of enzymatic browning (Khan, 2012).

The aim of our work was to assess an innovative pre-drying process (applying PEF and OD treatments, alone or in combination) for the valorisation of kiwifruit waste by the production of functional kiwifruit snacks.

MATERIALS AND METHODS

Raw materials

Undersized yellow kiwifruits *Actinidia chinensis* 'Jintao' with an average weight of 63 ± 1.6 g, a total soluble solids content of 13 ± 1 °Brix, and with a firmness of 66.5 ± 13.5 N, were provided by Jingold Consortium (Cesena, Italy). Before trials, the fruits were stored in refrigerated conditions ($4 \pm 1^\circ\text{C}$) for a period not longer than one week. Before processing, the fruits were manually peeled and cut into discs 3 mm thick and then subjected to OD and/or PEF treatments before the subsequent drying process.

Treatments

1. Pulsed electric fields (PEF).

PEF treatment was performed using a lab-scale pulse generator (Alintel srl., Bologna, Italy) connected to a cubic treatment chamber ($5 \times 5 \times 5$ cm) holding the sample and the parallel-plate electrodes. The PEF protocol consisted of an electric field strength of 200 V cm^{-1} (calculated as the ratio between the applied voltage and the distance between the electrodes), 1000 rectangular-shape pulses with a fixed width of $10 \mu\text{s}$, with a repetition frequency of 100 Hz. The total energy input was of 1.92 kJ kg^{-1} . Tap water with a conductivity of $421 \mu\text{S cm}^{-1}$ (conductivity meter, Crison Instruments, Barcelona, Spain) was used as the conductive medium in the treatment chamber.

2. Osmotic dehydration (OD).

The OD treatment was carried out by immersing the disc-shape pieces of kiwifruit in 40% (w/w) trehalose (Exacta + Optech Labcenter spa., Modena, Italy) solution at $35 \pm 1^\circ\text{C}$ for 150 minutes (1:4 product/solution ratio).

3. Drying process for snack preparation.

Each of the four samples (Untreated (C), PEF treated (PEF), OD treated (OD), and PEF and OD combined (PEF-OD)) was subjected to hot air drying at 50, 60 and 70°C in a convective dryer (Pol-Eko-Aparatura SP.J., Wodzisław Śląski, Poland). The air velocity was set to 2 ms^{-1} , and an average of 21 discs were used for the preparation of each sample.

Physical analyses of snacks

1. Water activity.

Water activity (a_w) was measured using a dew-point water activity meter (Aqualab, Decagon Devices, WA, USA) at 25°C . Measurements were conducted in triplicate (i.e., 3 slices).

2. Drying kinetics.

The dimensionless moisture ratio (MR) was calculated as the gradient of the sample moisture content, following equation 1. The moisture content was determined gravimetrically by drying the samples at 70°C until the achievement of a constant weight (AOAC, 1996). Measurements were conducted in triplicate (i.e., 3 slices).

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

where M_0 , M_t and M_e are the moisture content (kg water / kg dry matter) at the beginning, at any time of drying and at the equilibrium (i.e., constant weight), respectively. The drying times were plotted as a function of MR.

3. Kiwifruit colour.

A spectrophotometer (Hurterlab, Virginia, USA) was used to investigate the snacks' colour following the different processing treatments applied. For each sample, the instrumental parameters L^* , a^* and b^* from CIE $L^*a^*b^*$ scale were measured. Measurements were carried out in 10 slices for each drying temperature, for each sample.

Chemical analyses of snacks

An extraction step was performed before the following chemical analyses. 0.5 g of dried kiwifruits were mixed and vortexed for 2 min with 10 mL of methanol 60% (w/w). Extractions were performed in triplicate (i.e., 3 extractions for each sample). The mixture was centrifuged for 10 min at 3000 x g and the supernatants were collected.

1. Vitamin C quantification.

The concentration of Vitamin C, measured as ascorbic acid, was determined following a redox titration, using an iodine solution (0.005 mol L⁻¹) and starch as indicator (Ciancaglini et al., 2001). The reaction oxidizes ascorbic acid to dehydroascorbic acid and reduces the iodine into iodine ions. When all the ascorbic acid present is oxidized, the excess of iodine reacts with the starch forming a blue complex indicating the end of the titration. Vitamin C content of kiwifruits snacks was expressed as mg of ascorbic acid per 100 g of dry matter of kiwifruits. The measurements were carried out in triplicates (i.e., 3 titrations).

2. Antioxidant capacity.

The antioxidant capacity of kiwifruits snacks was evaluated on the basis of scavenging the 2,2'-azino-bis-3-ethylbenzthiazoline-6-sulphonic acid (ABTS⁺) and 1,1-diphenyl-2-picrylhydrazylm (DPPH) radicals, following the methods described by Mannozi et al. (2020). The DPPH scavenging activity was determined by mixing 0.1 mL of kiwifruit extract, 0.2 mL of methanol and 0.25 mL of DPPH (Sigma-Aldrich, USA) and by measuring its absorbance at 517 nm. The ABTS⁺ scavenging activity was determined by mixing 30 µL of the fruit extract with 3 mL of ABTS (Sigma-Aldrich, USA) diluted solution (as described by Re et al. (1999)) and by measuring the absorbance at 734 nm every 30 seconds for a total of 6 min. The results of both essays were expressed as µmol Trolox/100 g of dry matter of fruits, and the measurements were carried out in triplicates (i.e., 3 measurements per essay).

Statistical Analysis

Significant differences between data were calculated by parametric analysis of variance (ANOVA) and Tukey multiple comparison, with a significance level of 95% (p<0.05). The analysis was performed using the software STATISTICA 6.0 (Statsoft Inc., UK).

RESULTS AND DISCUSSION

Drying kinetics

The variations of moisture ratio (MR) as a function of drying times at 50, 60 and 70°C are given in Figure 1. The treatments applied (i.e., PEF, OD, PEF-OD) in this study had an influence on the drying kinetics. In particular, the total drying time at the studied temperatures was affected and it varied as a function of both the pre-drying treatments and the drying temperature. The drying of kiwifruits started with an initial water activity of 0.98 and finished at 0.2-0.3, this water activity is typical of dried snacks. In Table 1 the end of the drying process (time) for each sample at each drying temperature is reported.

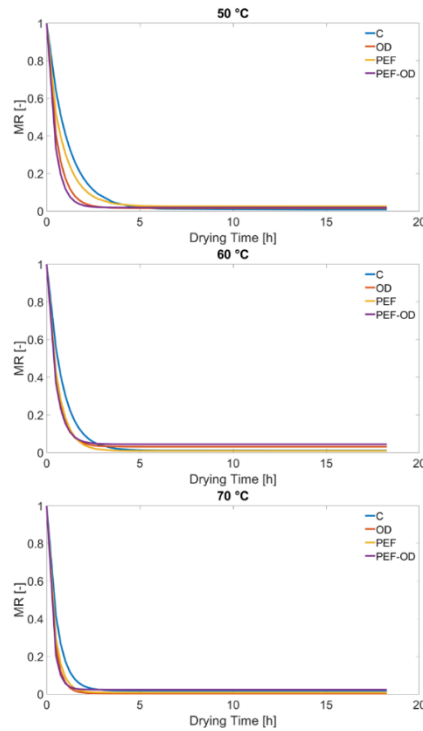


Figure 1. Moisture ratio (MR) of untreated (C) and osmotic dehydration (OD), pulsed electric field (PEF) and PEF-OD treated 'Jintao' kiwifruit snacks dried at 50, 60 and 70°C.

At the beginning of the drying process, it was possible to see the major differences between the samples and, these differences were more pronounced when the lowest (i.e., 50°C) drying temperature was used. For the samples dried at 50°C, the untreated sample (C) presented the highest MR after 1 hour of drying time, while the lowest MR corresponded to the kiwifruit treated by PEF followed by OD. The same trend was shown at the drying temperature of 60°C and 70°C.

Table 1. Total drying time [hours] of untreated (C) and osmotic dehydration (OD), pulsed electric field (PEF) and PEF-OD treated 'Jintao' kiwifruit snacks dried at 50, 60 and 70°C.

Drying Temperature [°C]	Drying Time [h]			
	C	OD	PEF	PEF-OD
50	16	6	6	6
60	8	5	4	6
70	7	4	3	5

Although after the first hour of drying the drying kinetics showed to be related to both the drying temperature and pre-drying treatment used, the endpoint (i.e., with $a_w = 0.3$) of the

drying process was reached faster when the kiwifruit slices were treated by PEF alone (Table 1). This trend could be explained by the mass transfer enhancement due to cell membrane electroporation. Pulsed electric field treatment, in fact, causes an increase in cell membrane permeability and, therefore, mass transfers (i.e., leakage of intracellular fluid into the extracellular space) could be positively affected (Donsì et al., 2010).

Colour

Table 2 shows the instrumental colour values, expressed as L* (lightness), a* (green-red index) and b* (blue-yellow index) of dried kiwifruit snack samples. It can be discerned that, in general, only slight modifications of colour parameters followed the treatments used. The combination of PEF and OD decreased the L* values of the products at all the drying temperatures tested. From the literature it can be seen that different tissues behave in different ways following PEF treatment. Wiktor et al. (2015) observed unchanged L* value or its slight decrease in apple samples, while increased values in carrot samples were observed. Tylewicz et al. (2020a) observed a decreased L* values in strawberry and kiwifruit samples following PEF, OD and PEF-OD treatments. In general, a decrease of the values of the colour parameters could be due to the leakage of pigments into the treatment solutions and due to the higher availability of the substrates for the enzymatic reactions (Wiktor et al., 2016). The PEF treated kiwifruits exhibited a slight increase of the chromatic parameter a* at the highest drying temperature. Nevertheless, the drying temperature of 60°C seems to be the more suitable for the maintenance of the fresh-like colour of all products.

Table 2. Color parameters (L*—lightness, a*—red index, b*—yellow index) of untreated (C) and osmotic dehydration (OD), pulsed electric field (PEF) and PEF-OD treated 'Jintao' kiwifruit snacks dried at the temperatures of 50, 60 and 70 °C. Results are expressed as mean values of n = 10 with the standard deviation (SD)

Sample	50°C					
	L*		a*		b*	
	Mean	SD	Mean	SD	Mean	SD
C	47.1 ^{aA}	2.1	5.5 ^{aA}	0.6	29.2 ^{aA}	2.7
OD	45.1 ^{aA}	4.0	4.6 ^{bA}	0.8	27.3 ^{aA}	2.8
PEF	43.9 ^{aA}	2.3	5.4 ^{aB}	0.8	26.1 ^{aA}	1.9
PEF-OD	38.7 ^{bAB}	3.7	5.0 ^{abA}	0.5	24.3 ^{aA}	2.1
Sample	60°C					
	L*		a*		b*	
	Mean	SD	Mean	SD	Mean	SD
C	43.5 ^{aB}	3.5	5.4 ^{aA}	0.9	28.8 ^{aA}	1.9
OD	43.2 ^{aAB}	4.8	5.3 ^{aA}	0.9	27.1 ^{aA}	3
PEF	43.1 ^{aA}	2.7	5.1 ^{aB}	0.5	24.8 ^{aA}	1.9
PEF-OD	40.6 ^{aA}	2.5	5.1 ^{aA}	0.8	24.1 ^{aA}	2.2
Sample	70°C					
	L*		a*		b*	
	Mean	SD	Mean	SD	Mean	SD
C	43.3 ^{aB}	5.8	5.1 ^{aA}	0.9	26.0 ^{aA}	2.9
OD	42.5 ^{aB}	2.2	5.0 ^{aA}	1.0	26.2 ^{aA}	1.6
PEF	42.7 ^{aA}	2.3	6.1 ^{bA}	0.9	27.8 ^{aA}	1.7
PEF-OD	36.9 ^{bB}	1.8	4.8 ^{aA}	0.8	22.3 ^{bA}	1.1

Different lowercase letters indicate significant differences ($p < 0.05$) between all considered samples at each drying temperature
Different uppercase letters indicate significant differences ($p < 0.05$) of each sample at the three drying temperatures

Vitamin C

The content of vitamin C in the untreated and treated kiwifruit snacks dried at 50, 60 and 70°C is shown in Figure 2. The untreated sample showed the highest amount of ascorbic acid at all the drying temperatures tested. However, among the treated samples, the PEF treated showed the best retention of vitamin C when dried at 50 and 60°C, while at the highest drying temperature tested (70 °C) the OD sample showed a better vitamin C retention.

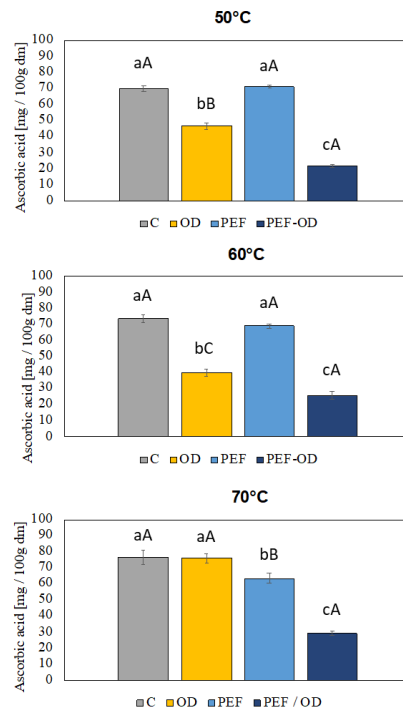


Figure 2. Vitamin C content, expressed as mg of ascorbic acid / 100g of dry matter, of untreated (C) and osmotic dehydration (OD), pulsed electric field (PEF) and PEF-OD treated 'Jintao' kiwifruit snacks dried at the temperatures of 50, 60 and 70°C. Results are expressed as mean values of n=3 with standard deviations (error bars). Different lowercase letters indicate significant differences ($p < 0.05$) between all considered samples at each drying temperature. Different uppercase letters indicate significant differences ($p < 0.05$) of each sample at the three drying temperatures.

Kiwifruits are, in general, rich in vitamin C, which represents the main nutritional compound (Huang et al., 2002), and for this reason could be used as a good indicator of the overall quality of processed kiwifruits. In our study, it is clearly shown a decrease of ascorbic acid content with the increase of pre-drying steps. Nevertheless, the PEF treated kiwifruits contained a similar amount of vitamin C to the untreated fruits, especially when 50 and 60°C were used. This behaviour could be explained as a consequence of the exposure to high temperatures for a shorter period of time for PEF treated samples (as shown in Table 1). In fact, it is well known that the exposure of various types of fruit to increasing high temperature and time could cause a dramatic decrease of vitamin C content (Piga et al., 2003).

Antioxidant capacity

The antioxidant capacity quantified by ABTS⁺ and DPPH assays was strongly affected by both the pre-drying treatment applied and the drying temperature. The highest retention of bioactive compounds was in the untreated kiwifruit snacks dried at 60°C and evaluated with the DPPH method. However, the ABTS⁺ scavenging activity increased for the PEF treated

kiwifruit snacks at all the drying temperatures, probably because of the shorter time necessary to complete the drying process (Table 1).

Table 3. Antioxidant activity by ABTS and DPPH assays of untreated (C) and osmotic dehydration (OD), pulsed electric field (PEF) and PEF-OD treated 'Jintao' kiwifruit snacks dried at the temperature of 50, 60 and 70°C. Results are expressed as $\mu\text{mol Trolox} / 100 \text{ g dry matter}$, and as mean values of $n=3$

Sample	ABTS ⁺ [$\mu\text{mol Trolox} / 100\text{g dm}$]					
	50°C		60°C		70°C	
	Mean	RSD	Mean	RSD	Mean	RSD
C	2075.6 ^{bB}	8.9	2833.5 ^{bA}	16.1	1207.8 ^{bC}	14.2
OD	1209.3 ^{dA}	4.4	966.6 ^{dA}	22	1309.8 ^{bA}	13.6
PEF	4500.2 ^{aA}	6	4284.1 ^{aA}	1.9	4726.8 ^{aA}	6.7
PEF-OD	1739.7 ^{cA}	8.9	1659.5 ^{cA}	13.3	1690.2 ^{bA}	9.8

Sample	DPPH [$\mu\text{mol Trolox} / 100\text{g dm}$]					
	50°C		60°C		70°C	
	Mean	RSD	Mean	RSD	Mean	RSD
C	2429.3 ^{aC}	4.5	6175.1 ^{aA}	2.8	2750.6 ^{aB}	8.7
OD	789.4 ^{bC}	3.9	3774.5 ^{bA}	5.7	2852.5 ^{aB}	8.3
PEF	2284.6 ^{aB}	6.6	2150.9 ^{cB}	4.4	2749.9 ^{aA}	13.4
PEF-OD	606.9 ^{cB}	8.7	916.9 ^{dA}	7.5	588.6 ^{bB}	8.7

RSD = % relative standard deviation

Different lowercase letters indicate significant differences ($p < 0.05$) between all considered samples at each drying temperature

Different uppercase letters indicate significant differences ($p < 0.05$) of each sample at the three drying temperatures

The discrepancies between the two essays in the resulted antioxidant capacity are related to the different capability of the assays used to detect certain bioactive compounds. It is generally reported that the ABTS⁺ method is more suitable for the determination of ascorbic acid scavenging activity, while the DPPH assay seems to be more appropriate for the identification of flavonoids (Del Caro et al., 2004). The same trend was previously described by (Tylewicz et al., 2020b), where strawberries treated by PEF at a specific energy input of 1.92 kJ kg^{-1} displayed a better retention of antioxidant compounds than strawberries subjected to lower energies. The increased antioxidant capacity in PEF treated snacks could be due to changes of the cell membrane that could lead to a greater release of bound bioactive compounds. The combination of PEF treatment with trehalose OD reduced the overall antioxidant capacity of kiwifruits, as reported previously by Tylewicz et al. (2020b).

CONCLUSIONS

The application of PEF and/or OD treatments influenced the drying kinetics of kiwifruit snacks. Both pre-drying treatments contributed to the reduction of the total drying time, an important aspect for energy saving in any future industrial applications. Moreover, the shortest drying times required for the OD and PEF treated samples could be beneficial for the production of fruit snacks with high functionality (i.e., higher concentration of bioactive compounds) and better overall quality. A further study would be of value to determine the costs for a possible industrial scale-up.

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