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Published Version:
Application of PEF- and OD-assisted drying for kiwifruit waste valorisation / Tylewicz, Urszula; Mannozzi, Cinzia; Castagnini, Juan Manuel; Genovese, Jessica; Romani, Santina; Rocculi, Pietro; Rosa, Marco Dalla. - In: INNOVATIVE FOOD SCIENCE & EMERGING TECHNOLOGIES. - ISSN 1466-8564. - ELETTRONICO. - 77:May 2022(2022), pp. 102952.1-102952.8. [10.1016/j.ifset.2022.102952]

This version is available at: https://hdl.handle.net/11585/863568 since: 2022-02-22

Published:

DOI: http://doi.org/10.1016/j.ifset.2022.102952

Innovative Food Science and Emerging Technologies

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This peer-reviewed accepted manuscript has been published in final form in INNOVATIVE FOOD SCIENCE & EMERGING TECHNOLOGIES Volume 77, May 2022, 102952, DOI https://doi.org/10.1016/j.ifset.2022.102952.

Application of PEF- and OD-assisted drying for kiwifruit waste valorisation

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Abstract

The production of dried snacks with high nutritional value represents a valid alternative to use the kiwifruit waste as undersized fruits, with a positive economic impact on the entire production chain. Therefore, this work aimed to evaluate the effect of pulsed electric field - PEF (200 V/cm) and/or osmotic dehydration – OD pre-treatments on drying kinetics (50, 60, 70°C), texture, colour, and sensorial properties of yellow kiwifruit snacks. The drying kinetics were significantly influenced both by applied treatment and drying temperature. The firmness of the kiwifruit snacks was improved by the combination of PEF/OD pre-treatments. In general, drying temperature of 70°C and the use of combined pre-treatments seem to be a good compromise to reduce drying time and obtain products with high quality in terms of colour, firmness, and overall acceptability.

Keywords

Kiwifruit waste valorisation, emerging processing, fruit snack, drying

Introduction

In the food system, the way of production and distribution, as well as the kind of foods we we choose to consume has a certain effect on the planet where we are living on and the society which we are living in. Moreover, the food waste valorisation, which is a part of the food waste management is an important issue and challenge for the food industries (Otles & Kartal, 2018). Concerning kiwifruit, agriculture and industrial processing of raw material generate a large amount of waste and kiwifruit by-products, including leaves, flowers, stems and roots (agricultural wastes) and culled fruit, pomace, peels and seeds as industry side stream (Chamorro et al., 2022; Sanz et al., 2021). Furthermore, kiwifruits with a weight lower than 65 g are considered waste and poorly paid as they are used in the production of fruit juices or in the energy supply chain (The Publications Office of the European Union (EC) No 1673/2004, 2004). Nevertheless, they are rich in vitamin C and other bioactive compounds, which contributes to their high antioxidant activity (Lintas et al., 1991), helping to fight against heart, vascular and central nervous system diseases, cancer and diabetes (Tyagi et al., 2015).

A recent study indicates that consumers prefer food with high nutritional properties and, at the same time, with elevated convenience and shelf-stability (Ramírez-Jiménez et al., 2018). In alternative to the high-calory snacks available on the market, dried fruits are considered a healthier substitute and are included in the dietary guidelines of many countries (Morais et al., 2018). Fruit snacks prepared by innovative technologies and valorising the resources already available could meet the challenges posed by the changes in eating habits and the ones related to the development a sustainable food system (Ciurzyńska et al., 2019; Jeszka-Skowron et al., 2017; Villalobos et al., 2018).

Fruit snacks are usually prepared by drying the fruit slices, and one of the most available and employed commercial drying methods is hot air drying. Hot air drying consists in the transfer of heat from the hot air to the product by convection, similarly, the evaporated water is transported to the air also by convection (Antal, 2015; Lewicki, 1998). However, the drying processes consume an appreciable part of the total energy used in the food industry, and it is very important to develop new hybrid drying technologies for energy saving and food quality preservation (Chou & Chua, 2001). Some pre-treatments could be used before the drying process such as osmotic dehydration (OD) and pulsed electric field (PEF) to accelerate the drying time and create attractive snack products (Mannozzi et al., 2020; Tylewicz et al., 2020; Witrowa-Rajchert et al., 2014). OD causes partial dewatering of the product at room temperature, due to the concentration gradient between the product and osmotic hypertonic solution, giving, therefore, the possibility to reduce the drying time (Bialik et al., 2020;

Dermesonlouoglou, Chalkia, Dimopoulos, et al., 2018) and to preserve the quality of the final product by making them more appreciable to the consumers, especially when a sour or underripe raw material is used (Nowacka et al., 2018; Panarese, Tylewicz, et al., 2012). Concerning the PEF application, those with high and moderate electric field strengths have been proposed for the enhancement of the drying process, allowing to decrease processing time, temperature, and energy consumption (Lammerskitten et al., 2020; Lebovka et al., 2007). The application of PEF pre-treatment at 10 kV/cm and 50 pulses provoked a decrease of drying time of up to 12 % on apples (Wiktor et al., 2013). Moreover, when these two mentioned treatments are combined further beneficial effects, in terms of drying time reduction, better preservation of the colour and bioactive compounds, were observed in carrots (Amami et al., 2008), apples (Amami et al., 2005), red bell pepper (Ade-Omowaye et al., 2003), kiwifruit (Mannozzi et al., 2020), goji berry (Dermesonlouoglou, Chalkia, & Taoukis, 2018) and cranberries (Nowacka et al., 2019).

In this context, to compare the pre-treatments effects on drying, mathematical modelling appears as a unique tool to help quantifying and interpreting the corresponding data, and evaluate rate constants (Le Feunteun et al., 2021). Moreover, the high complexity of products preparation and of the concerned processes (e.g. chemical and enzymatic reactions, physicochemical phenomena, mechanism of interaction between molecules/ingredients) is the main reason of the development of modelling in food engineering (Trystram, 2012). The literature presents different approaches for modelling various drying processes. In general, the models for the drying of food materials can be categorised into two major groups: (a) those involving empirical equations and (b) those based on the fundamental physics of the drying processes (Sabarez, 2015). Perhaps, the simplest empirical equation is the Newton model that only considers a kinetic constant (k). The higher the drying velocity, the higher is the constant k. As far as the Page model is concerned, it considers the kinetic constant (k) and introduces an empirical exponent (n) to overcome the shortcomings of the Newton model (also known as the exponential model) (Simal et al., 2005). Finally, the Weibull model considers the scale parameter (α) and the shape parameter (β). The scale parameter is the kinetic constant of the model and represents the time needed to accomplish approximately 63% of the drying. The reciprocal of α could be compared to the effective diffusion coefficient of the diffusion model since those two parameters are the kinetic constants for each model (García-Pascual et al., 2006). On the other hand, the shape parameter is related to the velocity of the mass transfer at the beginning of the drying (the lower is β, the faster is the drying rate at the beginning).

Therefore, this work aimed to evaluate the effect of PEF and/or OD pre-treatments, as well as their application sequence, on drying kinetics at different temperatures and on physicochemical parameters (firmness and colour) and sensorial properties of yellow kiwifruit snacks. Moreover, different models were compared to describe in the best way the drying kinetics and evaluate the effect of different pre-treatments on the velocity of the drying process.

2. Materials and Methods

2.1. Raw material handling

Yellow kiwifruits *Actinidia chinensis* (cv. Jintao) with a weight below 65 g were provided by Jingold Consortium (Cesena, Italy). The fruits were washed, hand-peeled and cut into slices. Seven 3±1 mm slices were obtained from each kiwifruit central part with the diameters in the range between 30 and 35 mm. For each combination of treatments, the amount of 21 kiwifruit slices was used, randomly selected from different kiwifruits. All obtained samples with related abbreviations are shown in table 1. The endpoint of drying process was established until a target water activity of 0.2 was reached, in order to ensure the microbial stability.

2.2. Pulsed electric field (PEF) treatment

Seven kiwifruit slices of each sample were placed into a rectangular treatment chamber (5 x 5 x 5 cm) and subjected to PEF treatment applying 1000 rectangular pulses with an electric field strength of 200 V/cm and a fixed pulse width of 10 µs. The pulses frequency and total treatment time were of 100 Hz and 10 s, respectively. Tap water with a conductivity of 421 µS/cm, determined by EC-Meter basic 30+ conductivity meter (Crison Instruments, s.a., Barcelona, Spain), was used as a conductivity medium inside the treatment chamber. The PEF treatments were applied using a pulse generator S-P7500 60A 8kV (Alintel SRL., Bologna). The total energy input was 1.92 kJ/kg.

2.3. Osmotic dehydration (OD) treatment

The OD treatment was carried out by immersing the kiwifruit in 40% (w/w) trehalose (EXACTA + OPTECH Labcenter S.p.A., Italy) solution for 150 min at 35°C, with the product: solution ratio of 1:4, as reported by Mannozzi et al., (2020).

2.4. Hot air drying

Untreated and differently pre-treated kiwifruit slices were subjected to hot air drying by using a hot air cabinet dryer (POL-EKO-APRATURA SP.J., PL). Three different drying temperatures were used 50, 60 and 70°C. The air velocity was 2 m/s, and an air renewal fee of 50% was used.

Table 1. Samples abbreviations and description of the pre-treatments applied for kiwifruit slices at each drying temperature (50, 60 and 70°C)

Sample code	Description
C	Non-treated samples (control)
OD	OD treated samples
PEF	PEF treated samples
OD/PEF	OD treated samples followed by PEF treatment
PEF/OD	PEF treated samples followed by OD treatment

2.4. Analytical determinations

2.4.1. Moisture content

Moisture content was determined gravimetrically by drying the samples at 70°C until a constant weight was achieved (AOAC, 1996).

The analyses were carried out in five repetitions from each sample at each drying temperature.

2.4.2. Modelling of drying kinetics

Three different mathematical models were applied to drying kinetics to evaluate the effect of different pre-treatments on the velocity of the drying process at each temperature (Table 2).

Table 2: Selected mathematical models used to fit the drying kinetics

Model Name	Model equation	Reference
Newton (Lewis)	$MR = e^{(-k.t)}$	(Sarimeseli, 2011)
Page	$MR = e^{(-k.t^{n})}$	(Sarimeseli, 2011)
Weibull	$MR = e^{-(\frac{t}{\alpha})^{\beta}}$	(Corzo et al., 2008)

Drying curves were plotted as a function of dimensionless moisture ratio (MR) during drying. The MR was calculated as the gradient of the sample moisture content at any time of drying (M_t, kg water/kg dry matter) to both initial moisture content (M_0, kg water/kg dry matter) and equilibrium moisture content (M_e, kg water/kg dry matter), according to the equation 1.

$$MR = \frac{M_t - M_e}{M_0 - M_e} \qquad \text{(eq. 1)}$$

Regression analysis was performed using the Curve Fitting app from Matlab. In order to explain the goodness of fit of each model, the correlation coefficient (R^2), root mean square error (RMSE) and sum squared errors (SSE) were calculated. The higher R^2 values (near 1), the lower RMSE and SSE indicate that the model fits better to experimental data.

2.4.3. Texture

The texture analysis was performed using a Texture Analyser mod. TA-HDi500 (Stable Micro Systems, Surrey, Godalming, UK), equipped with a 5 N load cell. A stainless-steel sharp blade was used for the cutting test. Force vs. distance curves were obtained using a test speed of 1.0 mm/s and the results are expressed in firmness or hardness (N).
The analyses were carried out in ten repetitions from each sample at each drying temperature.

2.4.4. Colour

The colour parameters were investigated using the CIE *L*a*b** scale in a Colorflex spectro-photocolorimeter (Hunterlab, USA) using the D65 illuminant and the 10° standard observer. The instrument was calibrated with a black and white tile (*L** 93.47, *a** 0.83, *b** 1.33) before the measurements. Results were expressed as green/red index-a*, blue/yellow index-b* and total colour difference (ΔE)

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad \text{(eq.2)}$$

where:
ΔL*, Δa*, Δb* are the differences of mean L*, a* and b* parameters, respectively, between non-treated and treated kiwifruit samples (Radojčin et al., 2015).
The analyses were carried out in ten repetitions from each sample at each drying temperature.

2.4.5. Sensory analysis

Untreated and differently pre-treated samples were subjected to sensory evaluation by a descriptive quantitative analysis (QDA) with a panel test of 12 trained panellists.

A sensory evaluation was done using the hedonic sensory scale (where 9 – like extremely and 1 – dislike extremely). The acceptability threshold value was set to 5 on the scale, according to the preliminary training. The attributes included integrity of the samples, colour, odour, taste intensity, sweetness, acidity, hardness and overall acceptability.

2.4.6. Statistical analysis

The data relating to moisture ratio, firmness and colour were evaluated and discerned by using an analysis of variance (ANOVA) followed by Tukey's HSD post hoc test to compare the means at the level of confidence of 95% ($p < 0.05$). The analysis was performed using the software STATISTICA 6.0 (Statsoft Inc., Tulsa, UK).

3. Results and discussion

3.1. Modelling of drying kinetics

As expected, the different pre-treatments and drying temperatures affected the drying kinetics. The MR after 60 min of drying is presented in table 3. For the samples dried at 50ºC, it can be seen that the control sample has a significantly higher MR as compared to the pre-treated samples, on the other hand, the lowest MR corresponds to the sample treated with PEF followed by OD, and just OD-treated samples. For the samples dried at 60ºC, the behaviour seems to be more or less the same, showing the highest values for the control sample, and the lowest for the PEF and PEF/OD samples ($p < 0.05$). Finally, also at 70ºC the highest value was obtained in the control sample, while no significant differences were observed between all the pre-treated samples.

Table 3. Moisture ratio of samples dried at different temperatures (after 60 min of drying). Different lowercase letters in columns indicate significant differences ($p < 0.05$) between each sample at the three drying temperatures.

Sample	50ºC	60ºC	70ºC
C	0.46 ± 0.05^{c}	0.33 ± 0.03^{d}	0.048 ± 0.003^{b}
OD	0.133 ± 0.002^{a}	0.182 ± 0.015^{b}	0.027 ± 0.002^{a}
PEF	0.32 ± 0.03^{b}	0.122 ± 0.012^{a}	0.021 ± 0.003^{a}
OD/PEF	0.270 ± 0.009^{b}	0.240 ± 0.014^{c}	0.0241 ± 0.0013^{a}
PEF/OD	0.09 ± 0.02^{a}	0.126 ± 0.012^{a}	0.025 ± 0.003^{a}

Mathematical modelling is important regarding the scale-shift of the process, from the laboratory to the industrial scale. The model that best fits the experimental data can be used to predict the processing time sufficient to dry the product to particular water content (Wiktor et al., 2013). In tables 4 and 5 the regression results of the three models evaluated are presented. All mathematical models presented a good fit of the experimental data; R^2 values were between 0.785 and 0.981; RMSE and SSE were in the range of 0.011-0.101 and 0.002-0.237 respectively.

Table 4. Goodness of fit of Newton, Page and Weibull model

Sample	Temp.	Newton			Page			Weibull		
		RMSE	SSE	R^2	RMSE	SSE	R^2	RMSE	SSE	R^2
C	50ºC	0.066	0.106	0.932	0.068	0.106	0.932	0.065	0.131	0.894
OD	50ºC	0.064	0.132	0.894	0.065	0.131	0.894	0.068	0.106	0.932
PEF	50ºC	0.101	0.237	0.785	0.071	0.111	0.899	0.026	0.016	0.983
OD/PEF	50ºC	0.032	0.020	0.984	0.032	0.019	0.985	0.071	0.111	0.899
PEF/OD	50ºC	0.037	0.027	0.972	0.031	0.019	0.981	0.031	0.019	0.981
C	60ºC	0.024	0.011	0.991	0.024	0.011	0.992	0.031	0.015	0.984
OD	60ºC	0.050	0.043	0.953	0.028	0.012	0.987	0.028	0.016	0.986
PEF	60ºC	0.020	0.009	0.992	0.011	0.003	0.997	0.025	0.008	0.990
OD/PEF	60ºC	0.064	0.103	0.897	0.019	0.009	0.991	0.032	0.019	0.985
PEF/OD	60ºC	0.057	0.078	0.915	0.026	0.016	0.983	0.030	0.018	0.987
C	70ºC	0.045	0.043	0.962	0.028	0.016	0.986	0.019	0.009	0.991
OD	70ºC	0.011	0.002	0.998	0.011	0.002	0.998	0.018	0.005	0.995
PEF	70ºC	0.020	0.006	0.994	0.012	0.002	0.998	0.011	0.002	0.998
OD/PEF	70ºC	0.032	0.018	0.983	0.018	0.005	0.995	0.024	0.011	0.992
PEF/OD	70ºC	0.044	0.028	0.967	0.025	0.008	0.990	0.012	0.002	0.998

Table 5. Constant values for each model

Sample	Temp.	Newton	Page		Weibull	
		k	k	n	a	b
C	50ºC	0.982	0.983	0.998	1.018	0.998
OD	50ºC	1.977	1.934	0.943	0.497	0.943
PEF	50ºC	1.314	1.399	0.450	0.474	0.450
OD/PEF	50ºC	1.323	1.322	0.925	0.740	0.925
PEF/OD	50ºC	2.486	2.121	0.637	0.307	0.637
C	60ºC	1.230	1.225	0.953	0.808	0.953
OD	60ºC	2.154	1.750	0.505	0.330	0.505
PEF	60ºC	1.897	1.740	0.755	0.480	0.755
OD/PEF	60ºC	1.596	1.440	0.475	0.464	0.475
PEF/OD	60ºC	2.197	1.724	0.379	0.238	0.379
C	70ºC	1.993	3.291	2.017	0.554	2.017
OD	70ºC	3.217	3.438	1.109	0.329	1.110
PEF	70ºC	2.793	3.971	1.593	0.421	1.594
OD/PEF	70ºC	2.401	3.824	1.841	0.483	1.841
PEF/OD	70ºC	3.510	2.406	0.261	0.035	0.261

Although the models could fit the relationship between average moisture content and drying time, they do not take into account the fundamentals of the drying process and their parameters have no physical meaning (Simal et al., 2005). Therefore, they cannot give a clear and accurate overview of the important processes and phenomena occurring during drying. Despite these considerations, the knowledge of the drying kinetics and subsequently the selection of an appropriate drying model can be used to understand and predict drying times and thus optimize the drying process for greater efficiency (Olanipekun et al., 2015).

In general, in Table 5 it can be seen that the lowest kinetic constant corresponds to the control sample, while when a pre-treatment like OD or PEF is applied, the drying process is accelerated. For almost all the models, at every temperature, the PEF/OD sample was the one that has the highest drying rate. In order to evaluate the relationship between the kinetic parameter and air-drying temperature, the kinetic constants were plotted against temperature and a linear regression was calculated (Figure 1; only the best two models are shown).

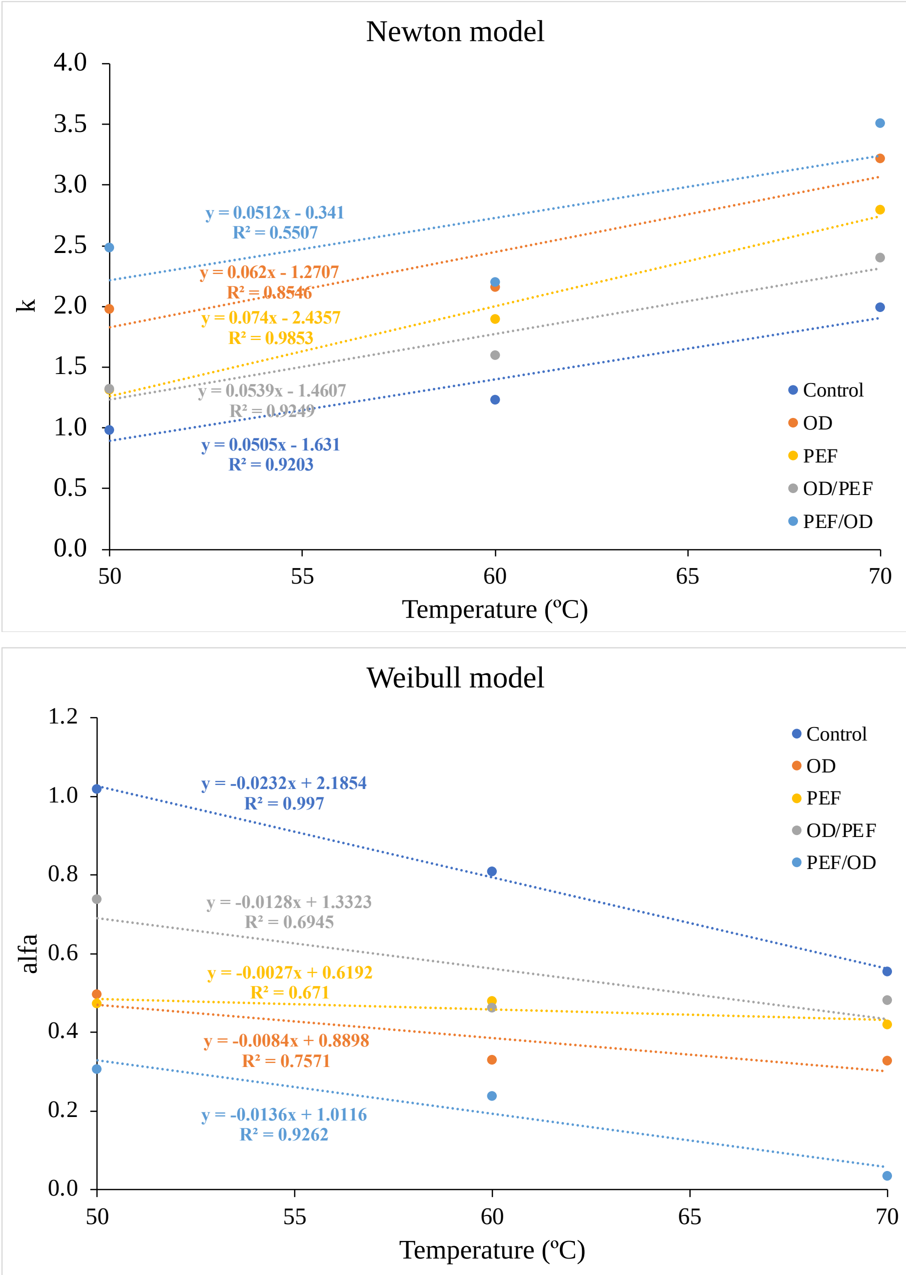


Figure 1. Kinetic parameter of Newton and Weibull models and air-drying temperature relationship.

As expected, the kinetic parameter has a linear correlation with temperature. These linear regressions could be used to predict the drying rate at other temperatures between 50-70ºC. Taking into account the correlation coefficient, the Weibull model explained better the relationship between temperature and drying rate for the control and PEF/OD sample while the Newton model fitted better the changes related to the temperature for OD, PEF and OD/PEF. Besides, the Weibull plot showed a different rate of change for the *alfa* parameter as the temperature increases. From the slope of each sample, it is possible to see that the greatest change on the kinetic parameter as the temperature change has been observed for the control sample, whereas for the pre-treated samples the temperature had a lower effect on the drying rate. This finding was also reported by Mannozzi et al., (2020), as they showed that the pre-treatments caused a higher reduction in drying time at 50ºC but the increasing temperature did not allow an increased reduction in the drying time. This trend could be related to the fact that the different pre-treatments change the initial solute/water content by osmotic dehydration and/or could enhance the mass transfer rate by PEF. As a consequence, the resulting drying response no longer depends only on temperature but even on the combined effect of temperature and applied pre-treatment.

3.2. Texture

Figure 2 shows the results of firmness obtained on differently treated kiwifruit slices after the drying process. Fresh kiwifruit samples had a firmness value of 6.42±1.09 N. Pre-treatment with OD slightly decrease the kiwifruit firmness to values of 5.53±1.26 N; however, this decrease was not statistically significant. Samples treated with PEF instead presented a significant decrease of firmness (1.59±0.21 N), which was even more pronounced in samples treated by the combined treatments OD/PEF and PEF/OD with the values of 1.26±0.08 and 1.43±0.12 N respectively.

As expected, after drying the firmness of all the kiwifruit samples increased due to the loss of water (Lewicki & Jakubczyk, 2004; Tylewicz et al., 2019). The relation between the increase of the firmness and stiffness with the decrease of the water activity was studied by Castagnini et al., (2020). They explained that this increase is due to the non-uniform distribution of the water molecules in the fruit matrix but rearranged within the structure. This anti-plasticizing effect of water is reflected in the reduction of the volume existing between the different cell structures, making more difficult the collapse of the structure. Moreover, the increase of hardness and crispness values could be related to the decrease of the samples T_g, due to the slight increase in the soluble solid phase (Zou et al., 2013). Kiwifruit pre-treated with both OD and PEF alone presented a lower firmness in comparison to the untreated dried samples. In general, the application of OD causes vacuole shrinkage, loss of cell turgor pressure and consequently softening of tissue, due to the structural changes such as distortion and decrease in size of cell walls, cell wall breakdown, increase of intercellular spaces, solubilizing of chelator-soluble pectin of the middle lamella . (Fernandes et al., 2008; Panarese, Laghi, et al., 2012). PEF treatment can also affect the plant tissue softening, due to the permeabilization of the cell membrane, which promotes the alteration of the membrane permeability (Tylewicz et al., 2017, 2019; Wiktor et al., 2016). In the present work, the combination of OD followed by PEF further reduced the firmness parameter, showing the lowest values, when the low temperature of drying (50 and 60°C) was used, while the inverted sequence (PEF followed by OD treatment) resulted in the highest firmness (apart for the samples dried at 60°C), compared to other pre-treated samples. Dermesonlouoglou et al., (2016) also observed that combined treatment with PEF and OD resulted in a higher firmness of semi-dried kiwifruits, relating this phenomenon with the humidification of the tissue by the cellular juice coming from the electroporated cells. Probably this thin layer of cellular juice formed on the kiwifruit tissue was sufficient to protect the cell from softening during OD. When PEF was applied on partially dewatered tissue (OD/PEF) probably, the cell disintegration was higher, promoting at the same time the lowering of the texture parameter.

In general, the highest temperature of drying (70°C) promoted a significant increase in the firmness of all the considered samples, followed by the samples dried at 50°C, while samples dried at 60°C showed the lowest firmness. Indeed, Lewicki & Jakubczyk, (2004) observed that the drying temperature could strongly influence the mechanical properties of the final products, however, they noticed this relationship only when the drying temperature increased from 70 to 80°C.

In the untreated samples, the increase in firmness was proportional to the increasing temperature. Similar results related to the crispness were observed by Cortellino et al., (2011) in pineapple samples, even if they tested the air-drying temperature increase from 70 to 80°C.

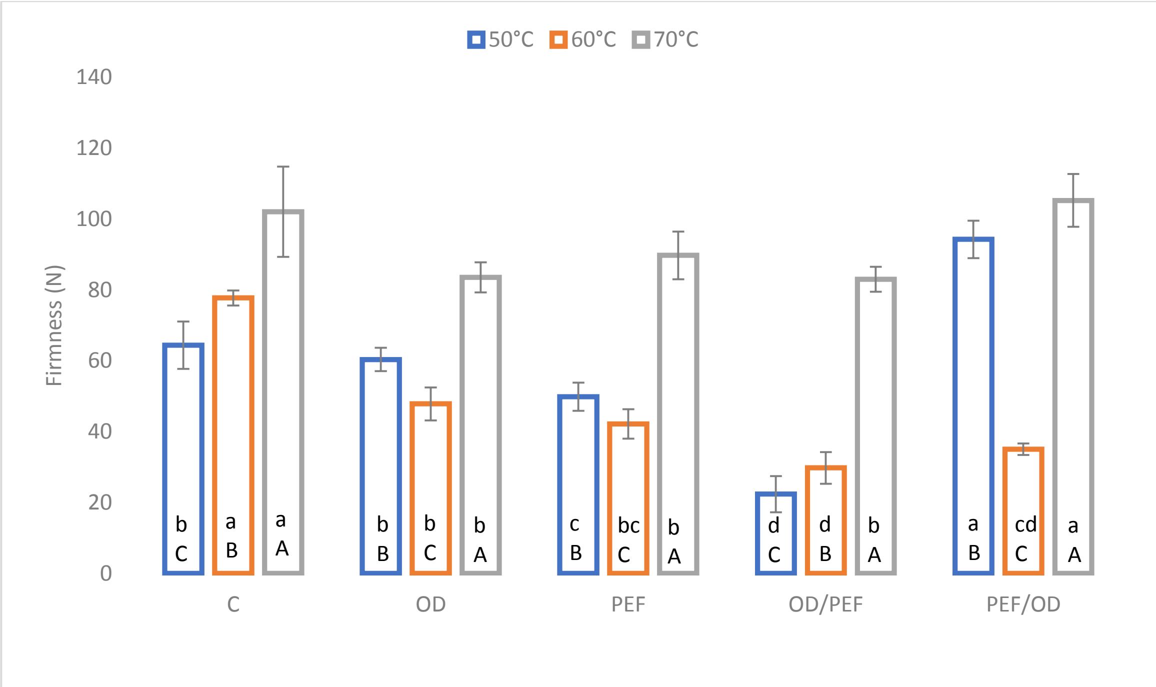


Figure 2. Firmness of untreated and differently pre-treated kiwifruit snacks dried at the temperatures of 50, 60 and 70ºC. Different lowercase letters indicate significant differences ($p < 0.05$) between all considered samples at each drying temperature, while capital letters indicate significant differences ($p < 0.05$) between each sample at the three drying temperatures.

3.3. Colour

Table 6 shows the colour parameters a* and b* and the total colour difference (ΔE), obtained on differently treated kiwifruit slices after the drying process. Fresh kiwifruit samples were characterized by a* and b* colour parameter values equal to 1.63±0.5 and 21.5±2.3, respectively. Drying of kiwifruit slices at all temperatures tested increased these values. As it can be seen from Table 6, the colour parameter a* did not change in the untreated and treated samples when dried at 50°C, while the significant decrease of this parameter, in the treated samples, were observed at 60°C. With the highest temperature of drying the PEF samples were those with the highest red index.

In general, the significant decrease of yellow b* index was observed in all treated samples when compared to the untreated one, showing the lowest values in the samples treated by combined treatment (OD/PEF and PEF/OD).

The ΔE is used to describe the overall changes in samples colour in reference to the untreated fresh sample. The visible changes are defined by the ΔE threshold, which usually depends on the initial optical properties of the product, and this threshold is in the range from 2 for products with low colour intensity like blood oranges Choi et al., (2002) to 6-7 for products with high colour intensity like blueberries (Stojanovic & Silva, 2007).

All the pre-treated samples presented lower colour differences in comparison to the untreated ones. This was particularly true for the samples dehydrated at low temperatures (50 and 60°C). The lowest colour differences were observed in samples treated with OD/PEF and dried at 50°C. OD treated dried samples showed ΔE values of 5.78 - 6.74. Similar values were observed by Nowacka et al., (2017) and Tylewicz et al., (2020) for kiwifruit subjected to the osmotic dehydration treatment.

When PEF treatment was applied alone or in combination with OD it was possible to observe that the highest drying temperature (70°C) promoted higher changes in the colour. The negative effect on kiwifruit colour related to the combination of PEF pre-treatment and high drying temperature could be due to the electroporation of the cell membrane, which caused both the increased release of enzymes and their substrates for the enzymatic browning reactions (Mannozzi et al., 2020) and pigments oxidation by thermal decomposition (Engin, 2020).

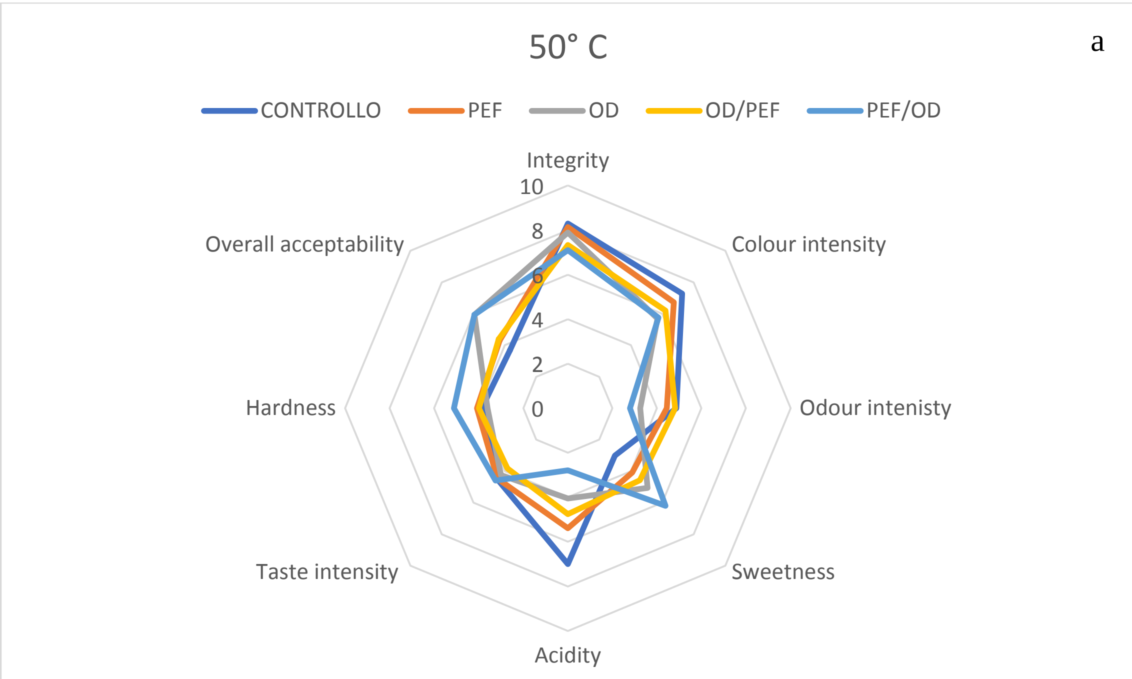
Table 6. Colour parameters a*, b* and total colour difference (ΔE) of untreated and differently pre-treated kiwifruit snacks dried at the temperatures of 50, 60 and 70ºC. Different lowercase letters in rows indicate significant differences ($p < 0.05$) between all considered samples at each drying temperature, while capital letters in columns indicate significant differences ($p < 0.05$) between each sample at the three drying temperatures.

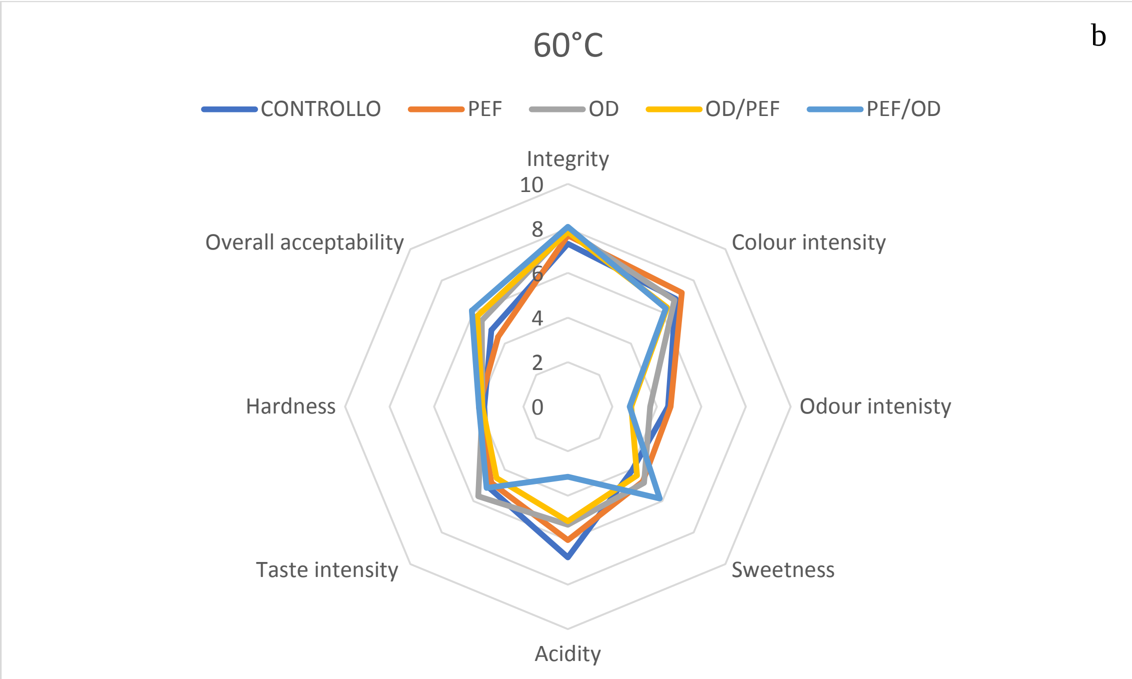
Sample	Temp.	a*	b*	ΔE
C	50ºC	5.5 ± 0.6 ^{aAB}	29 ± 3 ^{aA}	9.2 ± 0.5 ^{aA}
OD	50ºC	4.6 ± 0.8 ^{aA}	27 ± 3 ^{abA}	6.6 ± 0.3 ^{bA}
PEF	50ºC	5.4 ± 0.8 ^{aA}	26 ± 2 ^{bA}	5.9 ± 0.3 ^{cB}
OD/PEF	50ºC	4.8 ± 0.9 ^{aB}	22 ± 1 ^{cA}	4.4 ± 0.2 ^{dC}
PEF/OD	50ºC	5.2 ± 0.5 ^{aA}	24 ± 2 ^{bcA}	6.8 ± 0.5 ^{bB}
C	60ºC	6.4 ± 0.9 ^{aA}	29 ± 2 ^{aA}	8.7 ± 0.6 $^{a A}$
OD	60ºC	5.3 ± 0.8 ^{abA}	27 ± 3 ^{abA}	6.7 ± 0.4 ^{bA}
PEF	60ºC	5.1 ± 0.5 ^{bA}	25 ± 2 ^{bA}	4.8 ± 0.6 ^{cC}
OD/PEF	60ºC	4.8 ± 0.9 ^{bB}	24 ± 2 ^{bA}	5.7 ± 0.4 ^{cB}
PEF/OD	60ºC	5.1 ±0.8 ^{bA}	24 ± 2 ^{bA}	5.3 ± 0.3 ^{cC}
C	70ºC	5.0 ± 0.9 ^{bB}	26 ± 3 ^{aB}	6.0 ± 0.4 ^{bB}
OD	70ºC	4.9 ± 0.6 ^{bA}	25 ± 3 ^{aA}	5.8 ± 0.4 ^{bB}
PEF	70ºC	6.3 ± 0.9 ^{aA}	28 ± 2 ^{aA}	7.8 ± 0.6 ^{aA}
OD/PEF	70ºC	5.7 ± 0.4 ^{abA}	25 ± 2 ^{aA}	7.0 ± 0.2 ^{aA}
PEF/OD	70ºC	4.8 ± 0.8 ^{bA}	22 ± 1 ^{bA}	7.6 ± 0.7 ^{aA}

3.4. Sensory analysis

Figure 4 a, b, c shows the results of the sensory analysis carried out on differently treated kiwifruit slices after the drying process at the temperature of 50, 60 and 70°C, respectively. The samples treated with OD/PEF and then dried at 70°C was the one with the highest score for overall acceptability, while untreated control sample dried at 50°C showed the lowest acceptability level, under the acceptability threshold, which was fixed to 5 according to preliminary training. In general, with increasing the treatment temperature an increase in the overall acceptability of the samples was observed, regardless of the treatment used; while for samples dried at a lower temperature only the samples pre-treated with OD alone or in combination with PEF presented an acceptable value of this parameter, probably thanks to the increased sweetness of the samples, as observed by the panel.

Concerning the singular sensory parameters, the integrity of the slices was high for all the samples, suggesting that the preliminary operations did not affect significantly the cell structure. The untreated samples had the highest acidity, regardless of the drying temperature used, and a high score for parameters such as colour, odour and taste intensity. The last three parameters obtained also a good score in PEF and OD pre-treated samples alone. Kiwifruit slices pre-treated with OD followed by PEF, when dried at a lower temperature (50 and 60°C) showed an intermediate value of all parameters, while when dried at 70°C, in addition to having the highest score for the overall acceptability, showed also the highest texture and a good balance between the sweetness and acidity level. Finally, samples treated first with PEF and then with OD presented the highest sweetness and the lowest acidity and therefore were upper the overall acceptability threshold value, regardless the drying temperature applied.





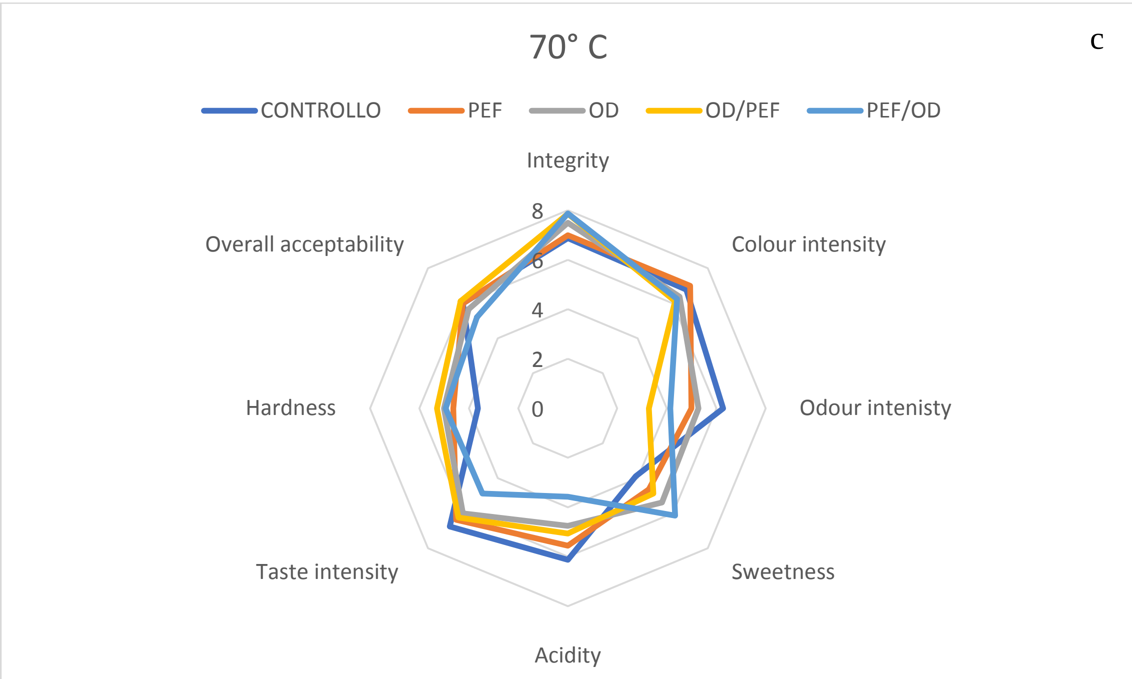


Figure 4. Sensory analysis of untreated and differently pre-treated kiwifruit snacks dried at the temperatures of 50 (a), 60 (b) and 70 (c)ºC.

4. Conclusions

The drying kinetics of kiwifruit snacks samples were significantly influenced both by the applied treatments and the drying temperature. Among the three different models (Lewis, Page and Weibull) used, the Lewis and Weibull models presented the best goodness of fit. In general, in the pre-treated samples drying response was no longer dependent only on temperature, as in the untreated ones, but also on the combined effect of temperature and applied pre-treatment. At every investigated temperature, the PEF/OD sample showed the highest drying ratio. Moreover, PEF/OD pre-treated kiwifruit snacks also presented the highest firmness and good overall quality and acceptability evaluated by the sensory panel, while the lowest impact on colour was observed in samples treated by PEF alone or applied after OD. This observation was more accentuated when low temperature of drying was used, while using the high temperature of drying (70°C) the differences among pre-treated samples were almost neglected.

The obtained results showed that by using the combination of PEF/OD as a pre-treatment to drying there is potential to achieve more sustainable processes, guaranteeing the nutritional features and the tasty flavour of obtained fruit snack products.

Acknowledgements

Financial support for this project was provided by Emilia-Romagna Region within the PSR 2014-2020 Project (Focus Area 5 C).

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Application of PEF- and OD-assisted drying for kiwifruit waste valorization

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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:

Credit Author Statement

All the authors contributed in the same way to the development of the research presented in this article.