

## Research Article

# Enrichment of Apple Slices with Bioactive Compounds from Pomegranate Cryoconcentrated Juice as an Osmodehydration Agent

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Pomegranate juice is an important source of bioactive compounds, and cryoconcentrated juice is an interesting osmodehydration agent to enrich a vegetal matrix. This investigation aimed to incorporate bioactive compounds from pomegranate cryoconcentrated juice into apple slices using osmodehydration (OD) assisted by pulse vacuum (PV) and ohmic heating (OH). The apple slices ( $3 \times 4 \times 0.5$  cm) were osmodehydrated using a 47 °Brix pomegranate cryoconcentrated juice at 30, 40, or 50°C for 180 min with an electric field of 6.66 V/cm (50 V) and a 5 min pulsed vacuum. Over the time, all of the treatments applied to the apple slices increased the soluble solids and bioactive compounds compared with the fresh sample. PVOD/OH at 50°C had the highest content of total anthocyanin during processing, and the best results for the total flavonoids were obtained with OD/OH at 50°C and 40°C. The osmodehydration assisted by pulse vacuum and ohmic heating using a cryoconcentrated juice is a useful combined technique to acquire enriched vegetal samples with bioactive compounds.

## 1. Introduction

As consequences of changing lifestyle and eating habits, diseases such as obesity, cardiovascular problems, diabetes type II, hypertension, and cancer among others have increased in the last decades [1, 2]. These adverse effects have developed an interest in healthy food and the consumption of functional food [3]. Functional foods include bioactive compounds (BAC) that have health benefits and nutritional value. Vitamins, polyphenols, and minerals are examples of BAC [3].

Pomegranate (*Punica granatum* L.) recently has gained interest in the past few years because of its nutritional and antioxidant activities [4]. Pomegranate juice is a potential source of anthocyanins, flavonoids, organic acids, and ellagic acid [5–7]. Additionally, recently, pomegranate juice has

been used as a functional ingredient, for example, in fermented milk and smoothies [8, 9]. Therefore, its health benefits are associated with those chemical characteristics.

The process of enriching vegetables to create functional products with BAC has been achieved through the combination of emerging technologies such as cryoconcentration with ohmic heating (OH) and assisted techniques such as pulsed vacuum (PV) and osmodehydration (OD). In this context, the food industry must link consumer demands and these available technologies [10].

Cryoconcentration, also called freeze concentration, as mentioned above, is an emerging technology, which consists of entirely or partially freezing the liquid food solution for later separation of the ice fraction from the liquid [11]. Vitamins, as well as polyphenols, are thermolabile compounds, and by using freeze concentration, the high

nutritional value and organoleptic characteristics can be protected [12]. Therefore, the BAC present in pomegranate juice could be protected using this technology.

OH is a thermal process, in which energy is generated by the passage of an alternating electrical current that diffuses through the food [1]. PV has been widely used to obtain a rapid penetration of compounds in vegetable tissues and enriches fruits and vegetables with antioxidants, vitamins, and minerals, among others [13].

Osmotic dehydration is a process in which water is partially removed from the cellular material or product when exposed directly to a concentrated solution of solutes or hypertonic medium [14, 15]. It has the advantage of higher nutritional content compared with drying methods because it has a minimal effect on the components of the food matrix [15]. The type of osmotic agent used and its molecular weight or ionic behavior affect the kinetics of water elimination and the gain of solids [15]. The OD mass transfer occurs through a semipermeable cell membrane, which makes substantial changes to the tissue structure [16].

The OD applied to vegetables is commonly performed using sucrose or other osmotic agents such as salt; however, recently, Lech et al. [17] reported the use of a fruit juice as an alternative OD solution (commercial chokeberry juice), obtaining interesting results in the final vegetable product in terms of bioactive compounds and antioxidant activity. In addition, Cano-Lamadrid et al. [18] reported a similar use of fruit juices such as OD solutions in this case was used to improve the sensorial and antioxidant capacity of pomegranate cultivar Mollar de Elche, a popular Spanish pomegranate.

This investigation aimed to determine the incorporation of bioactive compounds from frozen concentrated pomegranate juice into osmodehydrated apple slices using pulsed vacuum and ohmic heating treatments and to evaluate the mechanical and optical properties of the enriched product.

## 2. Materials and Methods

**2.1. Sample Preparation.** Pomegranate (cv. *Wonderful*) and apples (cv. *Granny Smith*) were acquired in the local market (Chillán, Chile) during the same harvesting season (March 2017) and stored under refrigeration ( $\approx 5^{\circ}\text{C}$ ) until processing. The pomegranates were cut in half, and the seeds were removed manually for juice extraction and filtered to eliminate any residue from the fruit and be ready for the experimental procedure. Apples were cut into sizes of  $3 \times 4 \times 0.5$  cm and submerged in a solution of 2% citric acid and 1% ascorbic acid for 3 min to prevent oxidation. The pomegranate (cv. *Wonderful*) has a slightly acid sweet flavor, a flavor that is compatible with the apple used as a vegetable matrix to be osmodehydrated.

**2.2. Osmodehydration Agent.** Cryoconcentrated pomegranate juice (osmodehydration agent) was obtained as described by Orellana-Palma et al. [19] and Petzold et al. [20, 21] with modifications. Samples were frozen at  $-20^{\circ}\text{C}$  for 12 h and placed in a refrigerated centrifuge (Eppendorf

AG, model 5430R, Hamburg, Germany) operated at  $15^{\circ}\text{C}$  for 15 min for the first cycle and 10 min for the second and third cycles at a speed of 1878 RCF, until the juice reached 48 °Brix (value obtained at the end of cryoconcentration cycles). The final cryoconcentrated juice had the following phenolic content: total polyphenols of  $4953.64 \pm 95.48$  mg gallic acid equivalents/L, total anthocyanin of  $117.64 \pm 1.30$  mg cyaniding-3-glucoside/L, and total flavonoids of  $368.84 \pm 4.62$  mg catechin/L. For the optical parameters (CIE  $L^* a^* b^*$  coordinates),  $L^*$   $1.07 \pm 0.41$ ,  $a^*$   $4.45 \pm 0.24$ , and  $b^*$   $1.05 \pm 0.04$ .

**2.3. Osmodehydration Treatments Assisted by Pulsed Vacuum and Ohmic Heating.** Osmodehydration with atmospheric pressure (OD) or pulsed vacuum (PVOD) and conventional and ohmic heating (OH) at 30, 40, and  $50^{\circ}\text{C}$  were conducted using a thermoregulated bath, as described by Moreno et al. [22, 23]. Osmotic treatments were carried out in a stainless steel tank made with two concentric cylindrical electrodes (3.7 and 19 cm in diameter) and a nonconducting bottom, and the distances between them were 7.50 cm [24]. Pomegranate juice was exposed to an alternating current at 60 Hz and 50 V, generating an electric field  $E$  of 6.66 V/cm, given by the following equation:

$$E = \frac{V}{d} \quad (1)$$

The temperature during the ohmic heating treatments was controlled through a refrigeration system.

**2.4. Total Phenolic Content (TPC).** The total phenolic content was determined through a colorimetric method by Folin–Ciocalteu (FC) reagent [25] using gallic acid as the standard. Treated sample extracts (100  $\mu\text{L}$ ) were mixed with 7900  $\mu\text{L}$  of distilled water, 500  $\mu\text{L}$  of FC reagent, and 1500  $\mu\text{L}$  of sodium carbonate. The samples were incubated for 120 min before measurement at 760 nm in a spectrophotometer (Shimadzu Scientific 1600 UV/VIS, USA). The results were expressed as mg of gallic acid equivalents in 100 g of dry matter (mg GAE/100 g d.m.).

**2.5. Total Anthocyanin Content (TAC).** Total anthocyanin content was determined spectrophotometrically by a pH differential method using two buffer solutions, potassium chloride 0.025 M at pH 1 and sodium acetate 0.4 M at pH 4.5, to treat the sample extracts following the methodology of Lee [26] with modifications. One part of the extract was mixed with one part of the buffer, and measurements were made at 510 and 700 nm in a spectrophotometer (Shimadzu Scientific 1600 UV/VIS, USA). The results were expressed as mg of cyanidin-3-glucoside in 100 g of dry matter (mg cyanidin-3-glucoside/100 g d.m.).

**2.6. Total Flavonoid Content (TFC).** Total flavonoid content was determined using a spectrophotometric method, using (+)-catechin as the standard. The assay was carried out as described by Dewanto [27]. An aliquot (0.25 mL) of the

extract was mixed with distilled water (1.25 mL), and 75  $\mu$ L of sodium nitrite 5% solution was added. After 6 min, 150  $\mu$ L of 10% solution of hydrated sixth aluminum chloride was added and the mixture was allowed to stand for 5 more min. Afterwards, 0.5 mL of 1 M sodium hydroxide was incorporated. Distilled water was added until it reaches a volume of 2.5 mL. Spectrophotometric measurements were made at 510 nm (Shimadzu Scientific 1600 UV/VIS, USA). The results were expressed as mg of catechin/100 g of dry matter (mg of catechin/100 g d.m.).

**2.7. Sample Compositional Analysis.** Soluble solids ( $X_{ss}$ ) and moisture content ( $X_w$ ) were determined during the osmodehydration processing time, and the effects on water loss and mass, solid gain, and water activity ( $a_w$ ) were examined. Moisture content was determined according to the method defined by the AOAC (Association of Official Analytical Chemist, 2000). Samples, fresh and treated, were dried at 60°C in a vacuum oven (Lab Line Instruments Inc.) at 10 kPa. The solute gain was determined as described by Moreno et al. [23], taking 3 g of sample (fresh or treated) and 25 mL of distilled water and grinding with Ultra-Turrax (Ika-Werke, model T25 basic, USA). The solid content was measured using a digital refractometer (Leica Mark II, Buffalo, NY, USA). The  $X_{ss}$  and  $X_w$  contents were determined for both fresh and treated samples, and the compositional changes were calculated through the following equations:

$$X_{ss} = \frac{(M \cdot X_t^w + W) \cdot A}{M \cdot (100 - A)}, \quad (2)$$

$$X_t^w = \frac{W_0 - W_t}{W_0},$$

where  $W_0$  and  $W_t$  represent the sample weights at time 0 and  $t$ , respectively.  $W$  is the weight of the distilled water and  $A$  stands for the sample °Brix.

The net changes of the soluble solid and moisture contents ( $\Delta M_t^{ss}$  and  $\Delta M_t^w$ ) were calculated with the following equations:

$$\Delta M_t^{ss} = \frac{M_t X_t^{ss} - M_0 X_0^{ss}}{M_0}, \quad (3)$$

$$\Delta M_t^w = \frac{M_t X_t^w - M_0 X_0^w}{M_0},$$

where  $M_0$  and  $M_t$  stand for the sample weight at time 0 and  $t$ , respectively.  $X_0^{ss}$ ,  $X_0^w$ ,  $X_t^{ss}$ , and  $X_t^w$  are soluble solids (ss) and water (w) mass fractions at time 0 and  $t$ , correspondingly.

The water activity ( $a_w$ ) of samples was determined using a dewpoint hygrometer (Aqua Lab Model 4TE, Pullman, USA).

**2.8. Mechanical Properties.** The firmness of the samples was evaluated with a Texture Analyzer TA-XT (Stable Microsystems, Haslemere, UK), using a slice shear blade. The

mechanical parameter was considered as the maximum peak force and reported in N.

**2.9. Optical Properties.** The color of apple slices, fresh and treated, was measured with a spectrophotometer (Konica Minolta CM-500). The CIE  $L^* a^* b^*$  coordinates used a  $D_{65}$  illuminant and 10° observer as a system reference. The chroma ( $C^*ab$ ), hue ( $h^*ab$ ), and the color differential ( $\Delta E$ ) were calculated according to the following equations:

$$C^* = \sqrt{(a^{*2} + b^{*2})},$$

$$h = \tan^{-1}\left(\frac{b^*}{a^*}\right), \quad (4)$$

$$\Delta E = \sqrt{((a^* - a_0)^2 + (b^* - b_0)^2 + (L^* - L_0)^2)},$$

**2.10. Statistical Analysis.** The experiment was carried out using a randomized factorial design ( $4 \times 3$ ) considering the osmodehydration treatments and temperatures as the primary sources of variance (Figure 1). The results were subjected to analysis of variance (ANOVA) and least significant difference test (LSD) using Statgraphics Centurion XVI software with  $p \leq 0.05$ . Measurements were done in triplicate, except for the mechanical properties, which were tested six times.

### 3. Results and Discussion

**3.1. Total Phenolic Content (TPC).** Figure 2 shows the TPC of the apples treated over the osmodehydration time. The PVOD/OH treatment at 30°C had a higher TPC (Figure 2(a)) over time (180 min), increasing to twice the initial value, followed by PVOD/OH at 50°C (Figure 2(b)). This behavior is connected with that of the bioactive compounds from the cryoconcentrated pomegranate juice used as a osmodehydration agent; similar results and explanation were reported using chokeberry juice in the OD processing of carrot and zucchini [17]. The samples with the lowest phenolic retention were PVOD at 40°C and OD/OH at 50°C (Figures 2(b)–2(c)). Furthermore, the TPC decreased for all samples after 30 min, except for PVOD/OH at 30°C (Figure 2(a)); this decrease was attributed to the treatment combination, temperature, and time. Additionally, after 180 min, most of the treatments retained at least the initial value of TPC, except for PVOD at 30°C and 40°C. Such findings agree with those reported by Moreno et al. [23], in which for these osmodehydrated treatments, the initial content of polyphenols was reduced significantly during processing time compared with that of the fresh sample.

**3.2. Total Anthocyanin Content (TAC).** As mentioned by Mahmoud et al. [28], anthocyanin pigments are responsible for the pomegranate red color and for the color of the osmodehydrated apples. Figure 3 shows the total anthocyanin content during processing time. As observed, PVOD/OH at 50°C had the highest anthocyanin content,

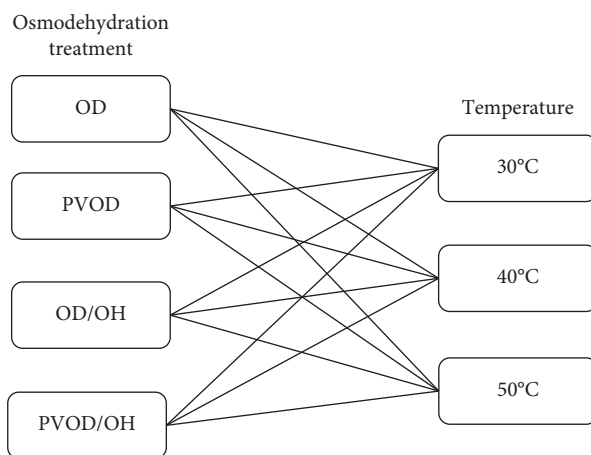


FIGURE 1: Experimental schema. Osmodehydrated treatments with cryoconcentrated pomegranate juice (47 °Brix) and temperatures. PVOD: osmotic dehydration with pulsed vacuum; OH: ohmic heating (OD/OH and PVOD/OH) at 6.66 V/cm.

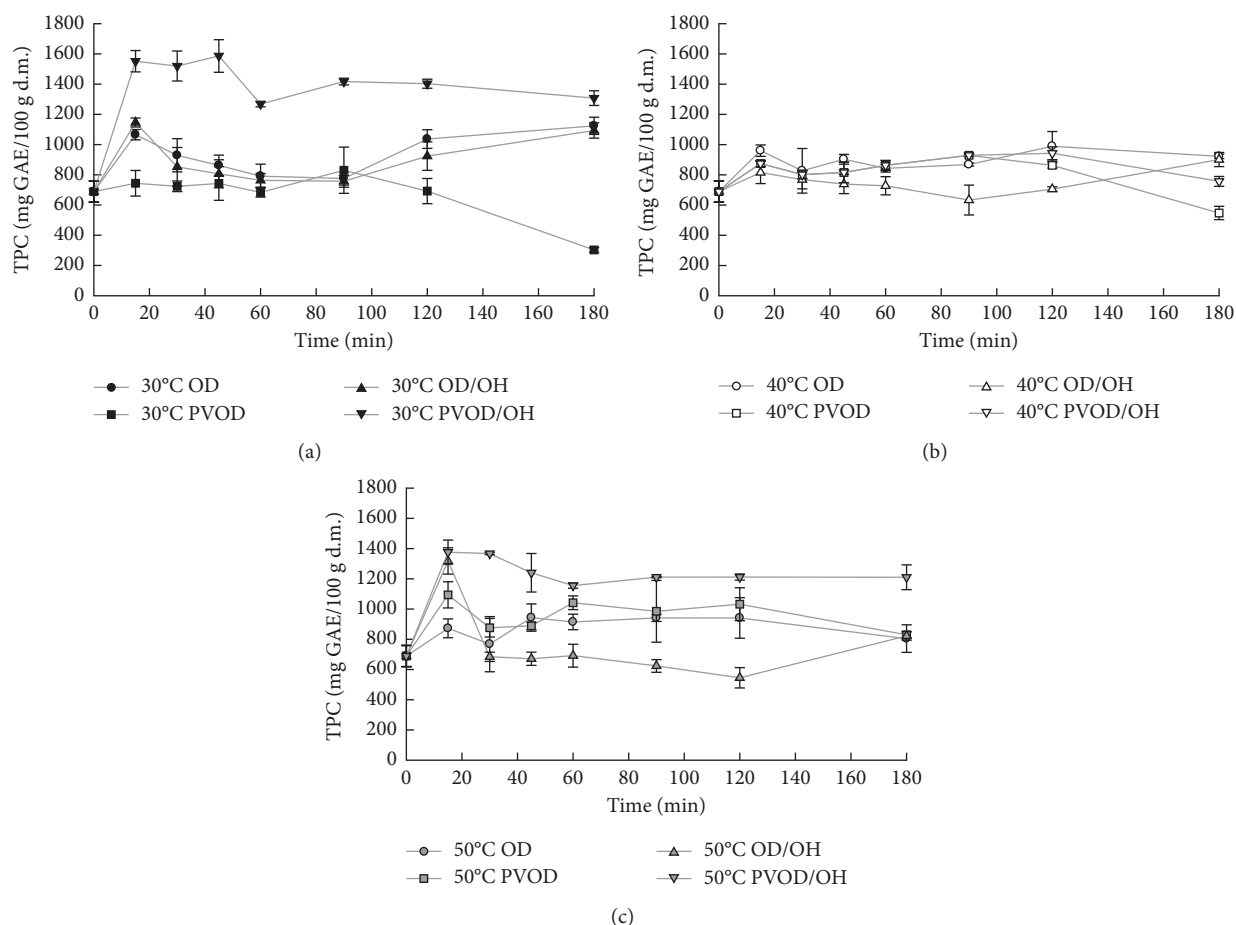


FIGURE 2: Total phenolic content (TPC) kinetics of osmodehydrated apple using cryoconcentrated pomegranate juice (47 °Brix) for 180 min. OD: osmotic dehydration at atmospheric pressure; PVOD: osmotic dehydration with pulsed vacuum; OH: ohmic heating (OD/OH and PVOD/OH) at 6.66 V/cm. (a) 30°C; (b) 40°C; (c) 50°C.

reaching a value near 117 mg of cyanidin-3-glucoside/L, very close to the anthocyanin content of the cryoconcentrated pomegranate juice (Figure 3(c)), followed by PVOD/OH at

40°C with 74 mg of cyanidin-3-glucoside/L (Figure 3(b)) and PVOD/OH at 30°C with 35 mg of cyanidin-3-glucoside/L (Figure 3(a)). This effect is associated with the temperature,

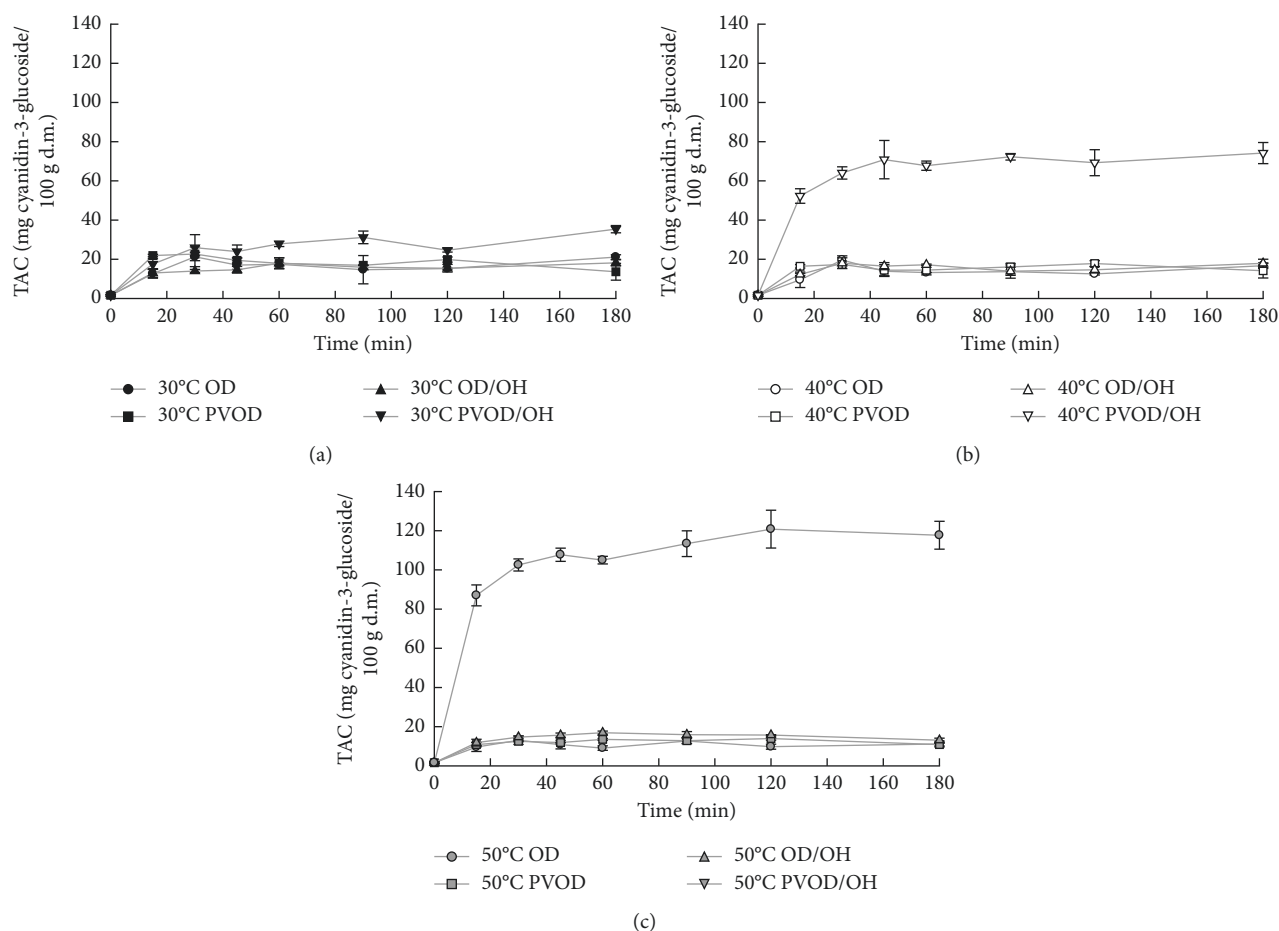


FIGURE 3: Total anthocyanin content (TAC) kinetics of osmodehydrated apple using cryoconcentrated pomegranate juice (47 °Brix) for 180 min. OD: osmotic dehydration at atmospheric pressure; PVOD: osmotic dehydration with pulsed vacuum; OH: ohmic heating (OD/OH and PVOD/OH) at 6.66 V/cm. (a) 30°C; (b) 40°C; (c) 50°C.

pulsed vacuum, and electroporation, which enables the osmodehydration agent (cryoconcentrated pomegranate juice) to enter the apple matrix pores [29, 30]. Reports showed that anthocyanins are less affected at 40°C than at 30°C and 50°C; this is due to a combination of temperature, time, pH, enzymes, stability, and physicochemical properties of these individual pigments [31, 32]. In the same study conducted by Kechinski et al. [33], it was demonstrated that anthocyanins were less likely to suffer from thermal degradation; the susceptibility to heat might be caused by the different forms of the pigments and the interactions of other components in the fruit. For the rest of the treatments, they present a decrease in the TAC after 180 min of treatment.

**3.3. Total Flavonoid Content.** Figure 4 displays the total flavonoid content kinetics. Similar to the TPC and TAC, flavonoids were best retained by OD/OH at 50 (Figure 4(c)) and 40°C (Figure 4(b)). The flavonoids had a drop at 90 min in most of the treatments. The loss of macromolecules such as flavonoid during heat treatment might be caused by temperature and time [34]. Wet thermal treatments may affect the cell's structure compromising the integrity and causing the migration of components, leading to damages by

leakage or breakdown by several chemical reactions [35]. For the 30°C treatment (Figure 4(a)), the OD presented better retention of flavonoids during the processing time.

**3.4. Compositional Changes and Water Activity.** Table 1 shows the compositional changes between the fresh sample and different treatments of osmodehydration after 180 min of processing. According to previous findings, osmotic dehydration with concentrated juice is more significant compared with osmotic dehydration with sucrose [36]. This behavior is in agreement with a recent study of Lech et al. [37], who conclude that the osmodehydration process is affected by the solution applied and the particular chemical properties of this solution. The combination of PVOD/OH at 40°C and 50°C had the highest solute gain, and PVOD at 30°C had more significant water loss and solute gain due to the diffusion and convection forces, both of which facilitate the mass transfer process. Application of pulsed vacuum eases the osmotic agent into the matrix pores and facilitates the water loss and has a beneficial effect on the kinetics, reaching equilibrium easily [23, 38]. Additionally, the combination of OD/OH encouraged more substantial concentrated levels in the samples than OD.



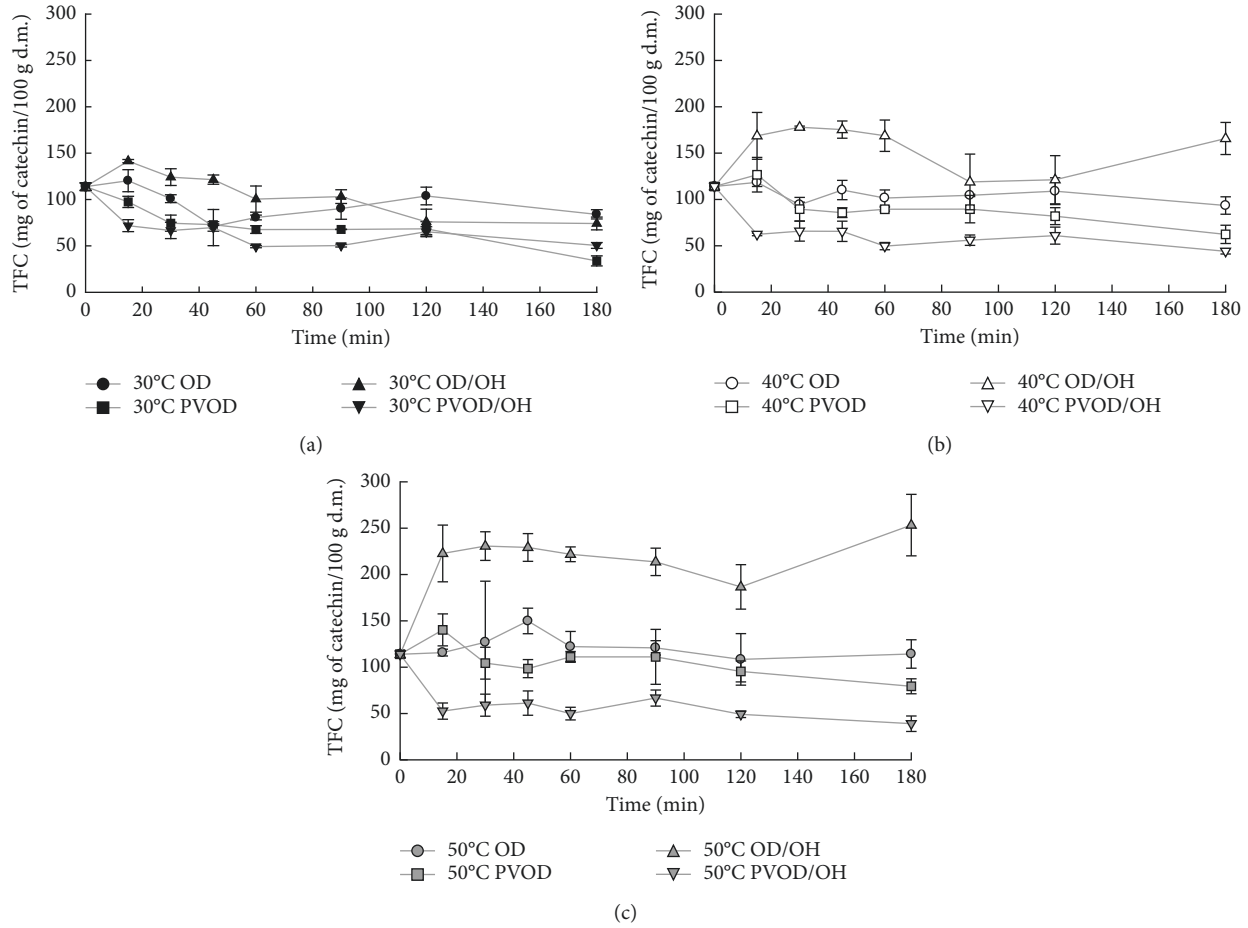


FIGURE 4: Total flavonoid content (TFC) kinetics of osmodehydrated apple using cryoconcentrated pomegranate juice (47 °Brix) for 180 min at. OD: osmotic dehydration at atmospheric pressure; PVOD: osmotic dehydration with pulsed vacuum; OH: ohmic heating (OD/OH and PVOD/OH) at 6.66 V/cm. (a) 30°C; (b) 40°C; (c) 50°C.

TABLE 1: Composition parameters of fresh and processed samples (processing time: 180 min), water mass fraction ( $X_w$ ), soluble solids mass fraction ( $X_{ss}$ ), water loss ( $\Delta M_t^w$ ), solid gain ( $\Delta M_t^s$ ), and water activity ( $a_w$ ).

Treatments	$X_w$	$X_{ss}$	$\Delta M_t^w$	$\Delta M_t^s$	$a_w$
Fresh	$0.85 \pm 0.01^g$	$0.22 \pm 0.02^a$	—	—	$0.98 \pm 0.09^g$
OD 30°C	$0.58 \pm 0.01^f$	$0.33 \pm 0.02^b$	$-0.32 \pm 0.04^c$	$0.63 \pm 0.12^d$	$0.91 \pm 0.01^{d,e}$
OD/OH 30°C	$0.56 \pm 0.01^{d,e,f}$	$0.77 \pm 0.02^d$	$-0.85 \pm 0.03^c$	$2.14 \pm 0.15^a$	$0.91 \pm 0.01^{e,f}$
PVOD 30°C	$0.56 \pm 0.01^{d,e,f}$	$0.90 \pm 0.12^e$	$-0.27 \pm 0.01^a$	$0.45 \pm 0.08^{d,e}$	$0.91 \pm 0.01^{c,d,e}$
PVOD/OH 30°C	$0.55 \pm 0.05^{c,d,e,f}$	$0.72 \pm 0.03^d$	$-0.27 \pm 0.01^a$	$1.88 \pm 0.08^{a,b}$	$0.92 \pm 0.00^f$
OD 40°C	$0.57 \pm 0.01^{e,f}$	$0.47 \pm 0.23^c$	$-0.66 \pm 0.08^b$	$1.50 \pm 0.06^{b,c}$	$0.91 \pm 0.01^{e,f}$
OD/OH 40°C	$0.52 \pm 0.01^{d,c,d}$	$0.79 \pm 0.04^d$	$-0.66 \pm 0.05^b$	$1.35 \pm 0.81^c$	$0.90 \pm 0.01^{c,d}$
PVOD 40°C	$0.54 \pm 0.00^{b,c,d,e}$	$0.82 \pm 0.03^{d,e}$	$-0.36 \pm 0.16^a$	$0.51 \pm 0.03^{d,e}$	$0.91 \pm 0.01^{d,e,f}$
PVOD/OH 40°C	$0.51 \pm 0.03^{a,b,c}$	$0.78 \pm 0.01^d$	$-0.31 \pm 0.24^a$	$1.27 \pm 0.22^{d,e}$	$0.90 \pm 0.01^{b,c}$
OD 50°C	$0.57 \pm 0.01^{e,f}$	$0.76 \pm 0.02^d$	$-1.15 \pm 0.01^d$	$2.08 \pm 0.45^{a,b}$	$0.92 \pm 0.01^f$
OD/OH 50°C	$0.47 \pm 0.02^{a,b}$	$0.80 \pm 0.06^{d,e}$	$-0.33 \pm 0.09^a$	$0.51 \pm 0.07^{d,e}$	$0.89 \pm 0.01^b$
PVOD 50°C	$0.52 \pm 0.01^{c,d,e}$	$0.79 \pm 0.02^{d,e}$	$-0.28 \pm 0.07^a$	$0.52 \pm 0.10^d$	$0.92 \pm 0.01^{e,f}$
PVOD/OH 50°C	$0.49 \pm 0.01^{a,b}$	$0.81 \pm 0.01^{d,e}$	$-0.35 \pm 0.01^a$	$0.65 \pm 0.03^d$	$0.87 \pm 0.00^a$

Different letters in each column indicate significant differences at  $p \leq 0.05$ , according to a LSD test. OD: osmotic dehydration at atmospheric pressure; PVOD: pulsed vacuum, both with conventional heating; OH: ohmic heating (OD/OH and PVOD/OH), electric field intensity at 6.66 V/cm (50 V).

In this case, the mass transfer in PVOD and PVOD/OH in comparison to OD is due to the unsteadiness of particles in the juice. Likewise, inadequate dissemination of the components may occur when gradient pressure in the

vegetable tissue provokes the irregular flow of the osmotic agent through the structure and consequently accumulates bioactive components in some areas [39], making the mass transfer harder in OD.

TABLE 2: Firmness and color determination in fresh and treated apples with three temperatures (30°C, 40°C, and 50°C).

Treatments	Firmness (N)	Color			
		$L^*$	$C^*ab$	$h^*ab$	$\Delta E$
Fresh	12.75 ± 3.53 <sup>c</sup>	64.38 ± 5.53 <sup>c</sup>	16.80 ± 3.16 <sup>d</sup>	96.48 ± 3.06 <sup>a</sup>	–
OD 30°C	26.34 ± 3.83 <sup>d,e</sup>	29.27 ± 2.12 <sup>b</sup>	30.63 ± 2.14 <sup>f</sup>	199.88 ± 0.69 <sup>g</sup>	45.14 ± 2.97 <sup>d</sup>
OD/OH 30°C	15.99 ± 1.05 <sup>c</sup>	26.43 ± 1.79 <sup>b</sup>	23.96 ± 5.48 <sup>e</sup>	198.31 ± 2.10 <sup>f,g</sup>	45.80 ± 3.54 <sup>d</sup>
PVOD 30°C	29.35 ± 4.19 <sup>e</sup>	22.25 ± 3.19 <sup>a,b</sup>	15.58 ± 7.28 <sup>c,d</sup>	194.91 ± 3.38 <sup>e,f</sup>	39.85 ± 1.43 <sup>b,c</sup>
PVOD/OH 30°C	10.87 ± 2.88 <sup>a,b,c</sup>	20.57 ± 1.18 <sup>a,b</sup>	3.84 ± 0.49 <sup>a</sup>	178.17 ± 2.80 <sup>b</sup>	48.91 ± 4.78 <sup>e,f</sup>
OD 40°C	14.61 ± 2.70 <sup>b,c</sup>	29.27 ± 2.12 <sup>a,b</sup>	30.63 ± 2.14 <sup>f</sup>	199.88 ± 0.69 <sup>g</sup>	47.89 ± 0.60 <sup>d,e</sup>
OD/OH 40°C	9.34 ± 0.61 <sup>a,b,c</sup>	24.70 ± 1.81 <sup>a,b</sup>	17.47 ± 3.30 <sup>d</sup>	197.50 ± 1.09 <sup>f,g</sup>	42.03 ± 2.63 <sup>c</sup>
PVOD 40°C	17.34 ± 2.97 <sup>c,d</sup>	21.63 ± 1.53 <sup>a,b</sup>	9.75 ± 3.12 <sup>b</sup>	191.83 ± 0.31 <sup>d,e</sup>	45.72 ± 0.76 <sup>d</sup>
PVOD/OH 40°C	8.57 ± 1.88 <sup>a,b,c</sup>	20.62 ± 0.51 <sup>a</sup>	3.45 ± 0.63 <sup>a</sup>	183.74 ± 1.49 <sup>c</sup>	51.82 ± 1.97 <sup>f,g</sup>
OD 50°C	2.88 ± 1.57 <sup>a</sup>	23.06 ± 1.14 <sup>a</sup>	13.97 ± 3.68 <sup>b,c,d</sup>	197.59 ± 1.53 <sup>f,g</sup>	50.65 ± 1.91 <sup>e,f</sup>
OD/OH 50°C	2.70 ± 0.17 <sup>a</sup>	22.96 ± 2.03 <sup>a</sup>	10.99 ± 1.19 <sup>b,c</sup>	196.69 ± 0.15 <sup>f,g</sup>	38.25 ± 2.00 <sup>b</sup>
PVOD 50°C	5.34 ± 1.75 <sup>a</sup>	21.01 ± 0.16 <sup>a</sup>	3.92 ± 1.08 <sup>a</sup>	188.74 ± 2.81 <sup>d</sup>	51.60 ± 1.99 <sup>f</sup>
PVOD/OH 50°C	6.27 ± 0.87 <sup>a,b</sup>	20.67 ± 0.72 <sup>a</sup>	3.06 ± 0.96 <sup>a</sup>	189.30 ± 2.62 <sup>d</sup>	54.73 ± 2.47 <sup>g</sup>

Different letters in each column indicate significant differences at  $p \leq 0.05$ , according to a LSD test. OD: osmotic dehydration at atmospheric pressure; PVOD: pulsed vacuum, both with conventional heating; OH: ohmic heating (OD/OH and PVOD/OH), electric field intensity at 6.66 V/cm (50 V) (processing time = 180 min).

The most significant water activity reduction was in PVOD/OH at 50°C, followed by OD/OH at 50°C in contrast to the fresh sample. This difference is attributed to temperature, pH, and electroporation, which promotes the gain from cryoconcentrated pomegranate juice and water loss [40, 41]. Other treatments also presented a significant difference compared with the fresh one.

On the other hand, it is important to mention the potential use of ultrasound as a technology that in general intensifies the mass exchanges and reduces drying times. In the case of ultrasound application in combination with the apple osmotic dehydration, Ciuzyńska et al. [42] demonstrated that it is an effective technology to accelerate the solid gain when using sucrose as an osmotic solution; however, when using chokeberry juice, it does not change.

**3.5. Changes in Optical and Mechanical Properties.** Table 2 shows the values obtained for the fresh and treated apple for the optical parameters:  $L^*$ ,  $a^*$ ,  $b^*$ , the hue angle ( $h^*ab$ ), chrome ( $C^*ab$ ), and change in color ( $\Delta E$ ). Previous studies have demonstrated that  $L^*$  (luminosity) increases with the osmotic treatment [40]. However, samples with a combination of PVOD and PVOD/OH have reduced  $L^*$  due to the concentration of anthocyanins from the pomegranate juice. This same effect was reported by Petzold et al. [21], in which the treated sample had a lower  $L^*$  than the fresh one. Temperature also contributed to this effect. Samples treated at 40°C and 50°C have the lowest value, and  $\Delta E$  was significantly higher in the treatments with lower  $L^*$ . This is due to the anthocyanin pigments being present in the pomegranate cryoconcentrated juice, especially for PVOD/OH at 40°C and 50°C (Section 3.2). On the other hand, we observed no significant difference in  $C^*ab$  of PVOD/OH treatments. For  $h^*ab$ , there was a significant difference between the fresh sample and the osmotically treated samples.

In general, the sample optical changes after the osmotic dehydration process could be connected with the plant

material used (i.e., cryoconcentrate pomegranate juice), agreeing with the previous results that used chokeberry juice as an osmodehydration solution [17, 18, 37].

The firmness values acquired from the mechanical test are shown in Table 2. The sample of PVOD at 30°C had the highest firmness value, which indicates a higher resistance [43]. The fresh sample differs significantly from the samples treated at 50°C. However, the values of treated samples at 40°C had no difference with the fresh one, as well as with that of OD/OH and PVOD at 30°C.

#### 4. Conclusion

The combination of pulsed vacuum and ohmic heating in the osmodehydration of apple slices at 30°C affected the retention of total phenolic content positively during processing time (180 min). The highest preservation of anthocyanin pigments was observed with PVOD/OH at 50°C, followed by the other two temperatures with the same type of treatment. On the other hand, the best results of flavonoids were obtained with OD/OH at 50°C and 40°C. Osmotic dehydration combined with pulsed vacuum and ohmic heating at 50°C and 40°C intensified the solid gain and water loss due to the diffusion and convection forces which accelerated the mass transfer process. PVOD/OH and OD/OH at 50°C had the most significant water activity mainly caused by the electroporation and temperature. The changes in color were significant in  $C^*ab$  (chrome) and  $L^*$  (lightness), for apple slices treated with PVOD and PVOD/OH, due to the retention of anthocyanins from the pomegranate cryoconcentrated juice. The highest firmness was observed in the sample of PVOD at 30°C. Therefore, our results suggest that the PVOD/OH process at 50°C for 120 min is the optimal treatment for osmodehydrated apples with pomegranate cryoconcentrated juice to obtain enriched apple slices. Finally, a possible future work is to study the proposed technology using other pomegranate cultivars such as the Mollar cultivars of Elche or Valenciana.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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