

Effect of Pretreatment and Process Parameters on the Chemical and Biochemical Properties of Moroccan Apricots (*Prunus armeniaca* L. Var. Canino)

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Abstract

Apricot preservation poses a challenge for farmers due to the fruit's short shelf life and susceptibility to spoilage and disease. Drying is a commonly used technique in the agri-food industry, but insufficient control in the drying process can result in changes to the fruit's appearance due to physiological damage during processing. This study aimed to control the drying process of *Canino* variety to obtain a high-quality product. Drying tests were conducted by varying several parameters: blanching time (1 min to 10 min), drying temperature (60 °C to 80 °C), relative humidity of drying air (maintained at 30% and 35%), and the use of anti-browning agents (Sodium metabisulfite ($\text{Na}_2\text{S}_2\text{O}_5$) and potassium bisulfite (KHSO_3)) with different concentrations (0.5% to 5%). 5-hydroxymethyl-furfural (HMF) and β -carotene were analyzed using chromatographic methods, while the phytochemical, enzymatic activities, and color characteristics were analyzed by spectroscopic methods. The results showed that the optimal conditions for drying *Canino* variety were blanching for 5 min, drying at 80 °C with 30% relative humidity and using metabisulfite at 5% concentration. These conditions resulted in a shorter drying time of 12 h, high levels of total phenols (486.67 ± 5.86 mg AGE/100 g) and β -carotene (2473.38 ± 20.49 mg AGE/100 g), and a better preservation of color. All samples met international standards for sulfur dioxide (SO_2) content.

Keywords

Drying apricots, Browning, Hydroxymethyl-furfural, Anti-browning agent, Color

Introduction

The apricot (*Prunus armeniaca* L.) is one of the oldest fruits cultivated by humans. It was introduced to North Africa by different civilizations, including the Phoenicians, Romans, and Arabs, due to the exchange of commercial products between the western and eastern parts of the Mediterranean region [1, 2]. Nowadays, the apricot is the third most widely grown stone fruit [3], with a total production of 3,914,719 tons in 2020 according to the FAO [4]. Morocco is classified as the 13th country regarding the total annual production of apricots, with a production of 101,612 tons in 2018 [4]. The most important apricot-growing areas in the country are the middle of Morocco (Marrakech region) and the north Atlas Mountains (Fes-Meknes region) [5].

While traditional varieties are almost the only source of production, new and interesting cultivars have been introduced in recent years to meet market requirements and satisfy consumers and industry demands [5]. However, apricots are seasonally perishable and have a short lifespan due to their high respiration rate and rapid maturation process [6]. Researchers and farmers have developed different methods to extend the lifespan of apricots, such as freezing and drying. Freezing involves reducing the temperature of the apricots to below their freezing point, which slows down the growth of microorganisms that can cause spoilage [7]. This method is relatively simple and requires only a freezer, it's essential to be aware of a significant drawback: the potential for freeze burn and browning of the apricot skin upon thawing [8]. This is why drying is preferred due to its effectiveness in reducing the moisture content and allowing safe storage at room temperature over a long period [9]. Sun drying has historically been the most commonly used drying method. However, industrial drying is now preferred due to its advantages in terms of reducing microbial contamination, controlling drying parameters, and ensuring consistent product quality in terms of sensory and nutritional attributes. Nevertheless, industrial drying can result in negative modifications, such as textural changes, chemical browning reactions (e.g., Maillard reaction) and enzymatic oxidations (e.g., enzymatic browning), if the process is not adequately controlled. The latter changes are responsible for surface browning and quality deterioration, which limits the acceptability of the dried product by the consumer. Therefore, there is a need to optimize the drying process of apricots to reduce browning reactions, limit microbial contamination, and to improve the quality of dried apricots [10]. The current work is oriented towards enhancing the drying process of the Moroccan apricot variety, improving their biochemical characterization, in order to obtain dried apricots of rich nutritional, organoleptic quality that meet International Standards for Dried Fruits. Additionally, no published studies on the optimization of the drying process of apricots from Morocco are available. Therefore, this work aims to involve adjusting process parameters such as blanching time, type and concentration of the anti-browning agent, and drying conditions (temperature and relative humidity) in a stepwise to achieve optimal results for enhancing the quality of Moroccan dried apricots.

Materials and Methods

Chemicals

All chemicals used in this study were purchased from Sigma Aldrich, except otherwise stated in the text.

Fruits origin and sampling

Apricots (*P. armeniaca* L. Var. *Canino*) were randomly collected at their commercial ripe state from different Moroccan localities: El Ksabi and Enjil (Boulemane province), Lmenzel (Sefrou province), Mibladen (Midelt province), and Loudaya (Marrakech province) (Table 1).

They were collected between “periods” in three replicates from the biggest local market. The fruits were carefully selected for their color, firmness, and the absence of visual defects, packed in polyethylene bags, and then stored at 4 °C prior to processing or analysis.

Pretreatment of apricots

Apricot fruits are prone to deterioration and rapid enzymatic browning. Hence, we have assessed the effect of blanching time on the enzymatic browning after sorting and homogenizing the fruits samples. Later on, anti-browning chemicals of commercial use have been investigated for enhancing the final product's quality.

Cleaning, sorting, and calibration

Collected samples were thoroughly cleaned up with tap water, let to dry on filter paper, manually checked for the presence of defects and deteriorations, and then intact ones were sorted using a laboratory vernier caliper to select a homogeneous size range for samples.

Blanching

Clean, fresh apricots were blanched in a boiling water bath set at 90 °C. Three different blanching times (1, 5, and 10 min) were tried to assess the effect on enzymatic browning of the fruits in their fresh form and prior to any drying of chemical treatment. The deactivation of polyphenol oxidase (PPO) and peroxidase (POD) enzymes was the main target of this step.

Table 1: Characterization of fresh apricots (Var. *Canino*) at commercial maturity before the drying process from different localities.

Locality	Water content (%)	pH	Acidity %	°brix	TPC (mg AGE/100 g)	β-carotene (µg/100 g)
Laqsabi (Boulemane)	85.95 ± 4.10 ^a	3.69 ± 0.16 ^{b,c}	0.61 ± 0.02 ^b	12.33 ± 1.86 ^a	602.25 ± 41.40 ^b	1385.14 ± 40.57 ^c
Lawdaya (Marrakech)	82.05 ± 1.20 ^a	3.97 ± 0.12 ^c	0.57 ± 0.01 ^a	15.60 ± 0.99 ^b	526.00 ± 8.49 ^a	1288.68 ± 20.28 ^b
Midelt (Lmenzel)	84.83 ± 1.81 ^a	3.42 ± 0.19 ^{a,b}	0.61 ± 0.02 ^b	12.50 ± 0.26 ^{a,b}	604.33 ± 15.04 ^b	1333.83 ± 17.58 ^{b,c}
Midelt (Mibladen)	82.98 ± 1.79 ^a	3.21 ± 0.15 ^{a,b}	0.61 ± 0.01 ^b	12.43 ± 1.59 ^a	636.67 ± 21.01 ^b	1547.82 ± 15.00 ^d
Enjil (Boulemane)	79.94 ± 0.60 ^a	3.37 ± 0.09 ^a	0.63 ± 0.01 ^b	16.30 ± 0.26 ^b	580.33 ± 20.50 ^b	718.25 ± 41.16 ^a
Sig	n.s	***	*	***	***	***

Note: TPC: Total phenol content; Signification levels: *p < 0.05; **p < 0.01; ***p < 0.001; n.s. = non-significant p > 0.05; Column with the same letter belong to the same group.

Anti-browning treatment

Two chemicals of commercial interest were selected for this study, namely: $\text{Na}_2\text{S}_2\text{O}_5$ and KHSO_3 . Blanched apricots were soaked for 1 h at solutions of each anti-browning agent with concentrations of 0.5, 1, 2, and 5% each.

Drying experiments

Drying experiments were performed in a humidity chamber HCP 153 (Memmert, Germany), as stated in figure 1. Briefly, the fruits were dried at temperatures ranging from 60 to 80 °C and relative humidity of 30 to 35% to final moisture of 20 to 25%, indicating the end of the drying process.

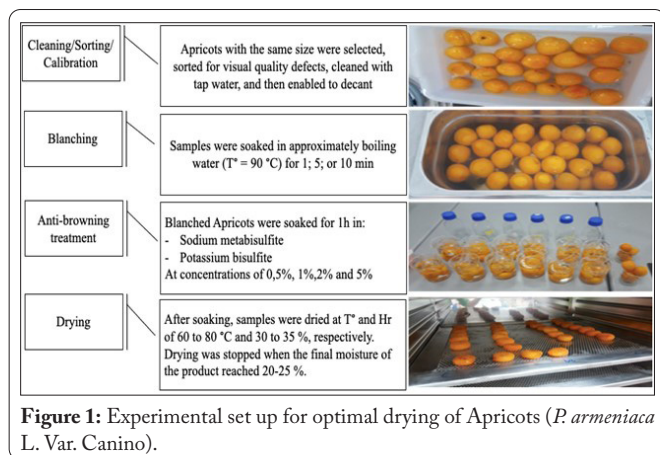


Figure 1: Experimental set up for optimal drying of Apricots (*P. armeniaca* L. Var. *Canino*).

Analytical indicators

Physicochemical properties

Surface color measurements

The surface color of fresh and dried apricots was measured with CIELab chromatic method using a CR:5 spectrophotometer (Konica Minolta, Japan). The lightness (L^*), redness (a^*), and yellowness (b^*) were measured. Saturation (Chroma, C^*), total color change (E^*), and Browning rate were calculated from L^* , a^* , and b^* color coordinates using the following equations [11]:

$$C^* = \sqrt[3]{(a^{*2}) + (b^{*2})} \quad (1)$$

$$E = \sqrt[3]{(\Delta L^{*2}) + (\Delta a^{*2}) + (\Delta b^{*2})} \quad (2)$$

$$\text{Browning rate} = \frac{L^* - L}{L^*} \times 100 \quad (3)$$

Water content

Water content was measured with a Md 83 moisture determination balance (Vibra, Japan) based on the evaporation weight loss method.

Water activity (a_w)

Water activity was determined at 25 °C using an AquaLab CX-2 a_w meter (Decagon Devices, USA).

pH and titratable acidity

Ten grams of apricots were rehydrated overnight with 90 g of distilled water at 4 °C, homogenized for 5 min, and then filtered through a muslin cloth. The filtrate was used for pH determination using a WTW pH meter (Inolab Level 1, Germany). Titratable acidity was determined according to the method described by [12], and results were expressed as % of citric acid equivalents.

Soluble solids

Total soluble solids (or °Brix) were estimated at 25 °C using a Pocket Digital refractometer (ATAGO Co LTD, Japan). Samples were homogenized and filtered before analysis.

Pretreatment efficiency

Percentage of Inhibition for Polyphenol Oxidase and Phenol Peroxidase Activities

Apricots were heated in a boiling water bath set at 90 °C between 1 min and 10 min. Subsequently, an enzymatic extract was prepared in MacIlvaine buffer according to [13] and then PPO and POD activities were measured as described by [14] and [15]. Percentage of inhibition rate was calculated as follows:

$$\% \text{Inhibition} = \frac{(AU_i - AU_f)}{AU_i} \times 100 \quad (4)$$

Where, AU_i : Enzymatic activity prior to pretreatment and AU_f : Enzymatic activity of blanched or dried apricots.

SO₂ analysis

The SO₂ content of the dried apricots was determined according to Monnier-William's distillation method [16]. The results were expressed as mg of SO₂ per kg of dried apricots.

Drying efficiency

Rehydration capacity

Dried apricots were rehydrated in distilled water at 25 °C for a maximum of 5 h. The approximate ratio of apricots and water was kept at 1:30 (w/v) [17]. The rehydration capacity, described as the percentage of water gain, was calculated from the sample weight difference before and after the rehydration as follows:

$$\% \text{Rehydration} = \frac{W_r - W_d}{W_d} \quad (5)$$

Where, W_r : Weight of rehydrated sample and W_d : Weight of dried sample before rehydration.

Determination of HMF

The HMF analysis was performed using high-performance liquid chromatography (HPLC). Briefly, in a 50 ml flask, 5 ml of 0.3 N oxalic acid were added to 5 g of apricot sample. The mixture was incubated for 60 min in boiling water bath. After incubation, 5 ml of 40% trichloroacetic acid were

added and completed with distilled water until the mark. The samples were filtered through a 0.45 µm HPLC filter and injected in HPLC ultimate 3000 equipped with a Lichrosorb RP18-5 column (250 x 4.6 mm, 5 µm). Samples were eluted using a methanol water solution (90:10, v:v) at a flow rate of 1.0 ml/min. The detection was done at 285 nm.

Nutritional quality

Quantitative determination of β-carotene by RP C30-HPLC with DAD-detection

β-carotene was extracted following the method described by [18], with minor modification. Five grams of sample were rehydrated in 30 ml distilled water at 4 °C overnight. This mixture was homogenized for 2 min with an ultra-turrax at 1000 rpm to obtain a thoroughly homogenized sample. A 2.5 g of homogenized sample was precisely weighed directly into a polypropylene centrifuge tube using an electronic balance. Calcium carbonate (0.250 g) was added as a neutralizing agent. 10 ml of extraction solvent (hexane/acetone/ethanol, 50:25:25), was added to the centrifuge tube, and was agitated on an orbital shaker at 220 rpm until the residue became completely colorless (30 min). 2.5 ml of distilled water was added to hasten the phase separation, followed by centrifugation at 9.400xg at +4 °C for 15 min. The solution was separated into distinct polar and nonpolar layers. The upper hexane layer containing β-carotene was transferred to an amber-colored vial. 150 µl of internal standard (Trans-β-carotene) was then added. Subsequently, it was evaporated to dryness under a stream of nitrogen. The residue was dissolved in 1 ml of methanol HPLC grade. The resulting extract was filtered through a 0.45 µm HPLC filter directly to an amber colored auto sampler vial. The filtered extract was then immediately injected to HPLC (HPLC-system Dionex ultimate 3000) with a quaternary pump, a diode array detector, a degasser and a thermostatted column compartment. The chromatographic data were recorded and processed on Chromeleon software. The separation was carried out on a C30 (reversed phase YMC-pack C30 (250 mm x 4.6 mm i.d., S-5µm, YMC, Schermbeck, Germany) at a flow rate of 1.0 ml/min. Sample injection volume was 25 µl, and column temperature was set at 30 °C. The detector was set at 450 nm.

Total phenols content (TPC)

Polyphenols were extracted according to the method described by [19]. Two grams of samples were homogenized with methanol (80%) for 30 min and centrifuged at 4500 tr/min. The supernatant was used to quantify a total phenolic compound according to the Folin-Ciocalteu method [20]. 0.25 ml of extract were mixed with 0.25 ml of Folin-Ciocalteu reagent and 0.50 ml of sodium carbonate (20%). The sample was thoroughly mixed and incubated in a water-bath at 37 °C for 30 min. Subsequently, the absorbance at 750 nm was measured by a spectrophotometer (V-630 UV-Vis Spectrophotometer JASCO (USA)). The TPC was expressed as mg of gallic acid equivalent per 100 g of dry weight (GAE)/100 g DW.

Statistical analysis

All the analyses described were performed in Triplicate (10 different apricots from each sample were homogenized

then 3 subsamples were taken for analyses). The statistical analyses were done by SPSS Software version 23. And results were presented as the mean value ± standard deviation.

Results and Discussion

Biochemical characterization of the collected fresh apricots

For the purpose of selecting apricots with optimal dehydration potential, five apricots *Canino* varieties apricots from different regions were collected (Table 1) and their biochemical characteristics and dehydration potential were tested (Table 1). All of the samples tested met the minimum requirement of 10 °brix set by the European Union market for apricot commercial maturity (R-EC No. 112/2001). This study revealed that the origin of the had a notable impact on their chemical and biochemical characteristics. There were significant differences ($p < 0.05$) in pH, % acidity, °Brix, TPC, and β-carotene content among the five apricots (Table 1). Brix degrees exhibited pronounced heterogeneity among apricots sourced from the different regions, ranging from $12.33 \pm 1.86\%$ in the Laqsabi region to $16.30 \pm 0.26\%$ in the Enjil region (Table 1). These results were consistent with those reported by [21] and [5]. The apricots from the Enjil region had the highest level of soluble solids (°Brix) ($16.30 \pm 0.26\%$) and a lower moisture content ($79.94 \pm 0.60\%$) than the other four varieties studied. The soluble solids content is an important quality factor that significantly influences the taste and flavor of the fruit [22]. The apricots collected from Midelt (Mibladen), had the lower value of pH (3.21 ± 0.09) and the largest quantities of phenolics compounds (636.67 ± 21.01 mg AGE/100 g) and β-carotene pigments (1.54 ± 0.01 mg/100 g). These amounts were lower than those reported in the varieties from northern Pakistan *Shai* and *Habi* with 10.12 and 18.13 mg of E.B.C./100 g of samples, respectively [21]. However, [23] reported much higher amounts in Turkish variety, (*Cologlu* and *Bursa* variety with 14.83 to 91.89 mg E.β.C./100 g DW). The results of this study explain the combined impact of various factors on pigments concentrations such as variety and pedoclimatic conditions. For polyphenols results were similar to those obtained by [23] and [24]. Based on the richness of phenolic compounds and pigments in the *Canino* variety from Midelt (Mibladen), it was chosen as the candidate for the remainder of this study.

Drying process optimization

Effect of blanching time on PPO and POD inhibition

Blanching is a pretreatment process that involves immersing the apricots in boiling water for a short period [25]. It can help to inactivate enzymes that cause browning and loss of color during drying. In this study, blanching times of 1 min, 5 min, and 10 min were tested to determine the optimal blanching time for *Canino* variety apricots. The impact of blanching treatments on PPO and POD enzymes inhibition percentage is investigated in figure 2. The result showed that the optimal blanching time was 5 min. Blanching treatments for 5 min at 90 °C significantly inactivated PPO and POD enzymes with an inhibition percentage of 99.91% and 99.27%, respectively, of the initial activity (Figure 2). The effect of blanching time on the quality of apricots can be significant. Blanching for 10

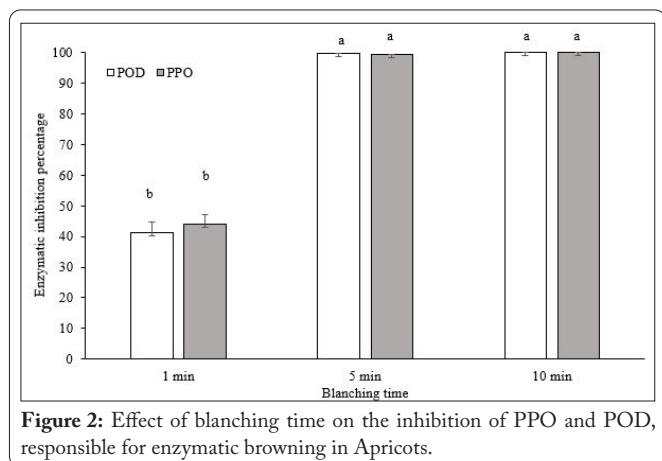


Figure 2: Effect of blanching time on the inhibition of PPO and POD, responsible for enzymatic browning in Apricots.

min effectively inactivated enzymes. But the apricots lose their texture at this duration. Similar result was found by [26, 27] on the effect of blanching duration on PPO and POD inhibition. During blanching, the heat denatures the PPO and POD proteins structures, the thermal energy introduced by blanching disrupts the weak bonds that hold the enzyme molecules together, resulting in the loss of their tertiary and quaternary structure, and thus their catalytic activity. Specifically, the heat causes the weak hydrogen and van der Waals bonds between the amino acid residues to break down, leading to the unfolding and loss of the protein's three-dimensional structure [28].

Effect of temperature and relative humidity on coloring

Color measurement is crucial for quality control in the food industry, especially for dried apricots. The color of dried apricots affects their overall quality, taste [29], and consumer appeal. The results show a significant difference in the Hunter Lab parameters (L^* ; a^* ; b^*) between fresh and dried apricots across all combinations. As depicted in figure 3a and 3b which represent the effect of temperatures and relative humidity at fixed anti-browning concentration (2%) on chromatic characteristics. The highest chromaticity and lowest intensity of color change (E) were observed at a higher temperature of 80 °C with a blanching time of 5 min for both anti-browning agent used ($\text{Na}_2\text{S}_2\text{O}_5$ and KHSO_3). This result is consistent with previous research [26], which suggests that higher drying temperatures help preserve color against degradation. Moreover, the study found that a blanching time of 5 min resulted in less color changes (E^*) and higher chromaticity (C^*) in dried samples, regardless of the drying temperatures tested. Additionally, a decrease in relative humidity from 35% to 30% had a similar effect, as shown in figure 3b. These results could be explained by the fact that blanching deactivates PPO and POD enzymes, which mediate the process of phenolic oxidation and browning phenomenon (Figure 2) [13].

Drying time and drying rate of apricots

Drying time was measured from the start of drying processes until reaching a value between 20% and 25% of moisture. The influence of temperature on the drying duration of apricots was evaluated under the following conditions: Blanching for 5 min, a relative humidity of 30%. The results of the experiment were presented in table 2, the analysis of variance revealed that temperature was the factor that significantly

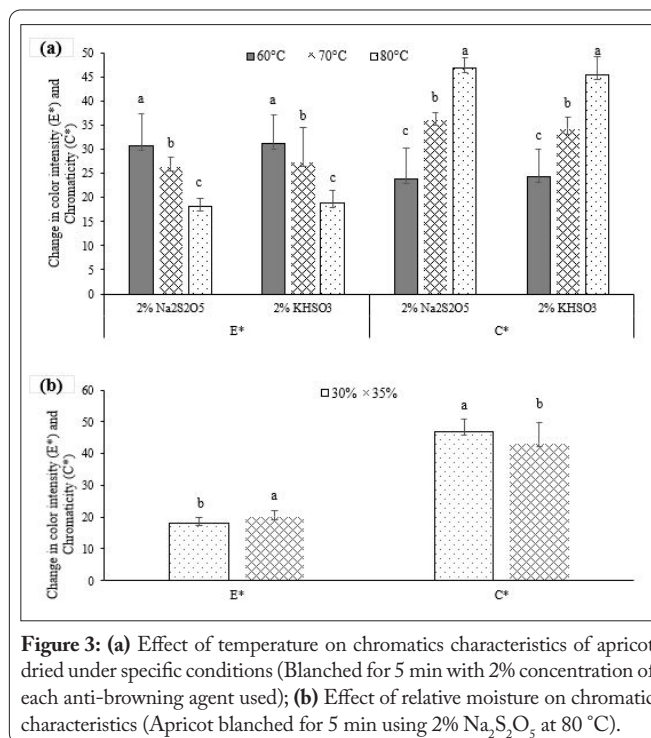


Figure 3: (a) Effect of temperature on chromatic characteristics of apricot dried under specific conditions (Blanching for 5 min with 2% concentration of each anti-browning agent used); (b) Effect of relative moisture on chromatic characteristics (Apricot blanched for 5 min using 2% $\text{Na}_2\text{S}_2\text{O}_5$ at 80 °C).

impacted the drying duration. There was a strong negative correlation (-0.942) between temperature and drying duration, with a minimum drying time of 12 h achieved at 80 °C, 30% relative humidity and 5 min of blanching. Additionally, the application of anti-browning treatments such as $\text{Na}_2\text{S}_2\text{O}_5$ or KHSO_3 significantly reduced the drying time of apricots (Table 2). Samples treated with these agents exhibited a shorter drying duration compared to the untreated samples (Table 2). Previous studies have demonstrated a similar effect in the drying of apricots [30], grapes, red pepper [31], and mulberry fruit [32]. Pre-treatment of apricots with anti-browning agents was found to enhance the moisture diffusivity, which is the movement of moisture through the apricots during the drying process. This result was consistent with the findings of [33]. The minimum recorded drying duration required to reduce the moisture content to less than 25% moisture was 12 h, which was achieved at a temperature of 80 °C, relative humidity of 30%, and blanching duration of 5 min (Table 2). Under these conditions, the highest dehydration speed of 9.89 g/h was recorded. A decrease in drying duration was observed with an increase in blanching duration and a decrease in relative humidity from 35% to 30%, which was consistent for all the temperatures tested. The aforementioned findings are in agreement with the observations of [34].

Quality evaluation of dried apricots samples

Moisture content, water activity, and rehydration capacity of dried apricots

Water activity (a_w) and water content are important parameters to consider for apricots as they affect the quality, shelf life, and safety of the product. a_w is a measure of the availability of water for microbial growth, chemical reactions, and physical change. Water content, on the other hand refers to the amount of water present in the dried apricots and it is a crucial factor affecting the texture, flavor, and color of dried

Table 2: Drying time, water activity, and rehydration capacity of dried apricot at different temperature (Blanching for 5 min and 30% of relative moisture).

			Drying time (h)	Water content (%)	Water activity	Rehydration capacity		
60 °C	Control	0%	23 ± 1 ^a	22.19 ± 2.86 ^{ab}	0.68 ± 0.03 ^b	57.68 ± 1.15 ^a		
		5%	22 ± 1 ^b	23.08 ± 0.99 ^b	0.63 ± 0.06 ^b	58.19 ± 1.92 ^a		
	Na ₂ S ₂ O ₅	1%		22.13 ± 0.82 ^{ab}	0.59 ± 0.05 ^a	59.02 ± 2.08 ^a		
		2%		22.28 ± 1.42 ^{ab}	0.60 ± 0.10 ^a	60.28 ± 3.15 ^b		
		5%		20.78 ± 1.11 ^a	0.55 ± 0.02 ^a	65.33 ± 2.18 ^b		
	KHSO ₃	0.5%		23.23 ± 0.78 ^b	0.66 ± 0.02 ^b	58.09 ± 3.12 ^a		
		1%		22.18 ± 0.55 ^{ab}	0.60 ± 0.05 ^a	56.23 ± 2.13 ^a		
		2%		22.02 ± 1.22 ^{ab}	0.62 ± 0.02 ^a	62.66 ± 4.18 ^b		
		5%		21.83 ± 1.05 ^a	0.58 ± 0.05 ^a	63.10 ± 2.69 ^b		
		Control		0%	18 + 1 ^a	22.97 ± 2.80 ^{ab}	0.65 ± 0.08 ^b	50.27 ± 2.10 ^a
70 °C	Na ₂ S ₂ O ₅	0.5%		17 ± 1 ^b	23.77 ± 0.31 ^b	0.66 ± 0.02 ^b	54.14 ± 3.15 ^a	
		1%	21.95 ± 0.52 ^{ab}		0.56 ± 0.02 ^a	53.78 ± 1.19 ^a		
		2%	22.93 ± 1.21 ^{ab}		0.67 ± 0.03 ^a	57.29 ± 2.34 ^b		
		5%	22.32 ± 1.58 ^a		0.60 ± 0.11 ^a	53.22 ± 1.98 ^b		
	KHSO ₃	0.5%	23.87 ± 0.50 ^b		0.68 ± 0.01 ^b	54.67 ± 2.75 ^a		
		1%	22.38 ± 0.29 ^{ab}		0.62 ± 0.02 ^a	55.67 ± 3.02 ^a		
		2%	21.55 ± 0.27 ^{ab}		0.59 ± 0.01 ^a	57.06 ± 1.99 ^b		
		5%	21.02 ± 0.97 ^a		0.58 ± 0.04 ^a	56.27 ± 3.29 ^b		
		Control	0%		13 ± 1 ^a	21.43 ± 1.57 ^{ab}	0.68 ± 0.07 ^b	52.59 ± 1.13 ^a
	80 °C	Na ₂ S ₂ O ₅	0.5%		12 ± 1 ^b	22.75 ± 0.50 ^b	0.64 ± 0.03 ^b	52.33 ± 1.67 ^a
1%			21.69 ± 0.91 ^{ab}	0.57 ± 0.02 ^a		53.97 ± 2.87 ^a		
2%			22.15 ± 1.65 ^{ab}	0.57 ± 0.04 ^a		52.94 ± 1.60 ^b		
5%			20.65 ± 1.32 ^a	0.53 ± 0.06 ^a		55.48 ± 1.90 ^b		
KHSO ₃		0.5%	22.37 ± 0.76 ^b	0.61 ± 0.04 ^b		52.29 ± 2.03 ^a		
		1%	22.05 ± 1.02 ^{ab}	0.58 ± 0.05 ^a		53.67 ± 2.89 ^a		
		2%	21.40 ± 1.37 ^{ab}	0.56 ± 0.06 ^a		56.49 ± 2.30 ^b		
		5%	21.52 ± 0.90 ^a	0.56 ± 0.02 ^a		56.57 ± 3.45 ^b		
		Sig Temperature				***	ns	ns
Sig Concentration			ns	**		***	***	

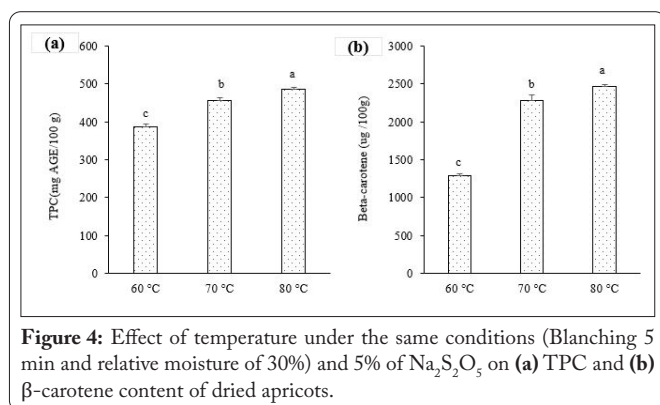
Note: Signification levels: *p < 0.05; **p < 0.01; ***p < 0.001; n.s = non-significant p > 0.05; Column with the same letter belong to the same group.

apricots [35]. The results (Table 2) showed that the moisture contents and aw values of apricots ranged from 20.65 ± 1.32% to 23.87 ± 0.50% and 0.53 ± 0.06 to 0.68 ± 0.001, respectively. Those results are in accordance with the Codex standard for dried apricots [36], which specified a maximum moisture content of 25% when additives such as Na₂S₂O₅ were used. In these experiments, the moisture levels in all treated samples never reached the maximum limit specified in the Codex standard (maximum moisture content of 25%) [36], indicating that the drying process was successful in producing high-quality and safe dried apricots. Rehydration of dried apricots is an important factor to consider and an important tool in evaluating the quality and freshness of dried apricots. When apricots are dried, they lose their moisture content, which can affect their texture, flavor, and nutritional value. Rehydration capacity testing helps determine how well the dried apricots can absorb water and regain their original texture and flavor [37]. Several factors can impact the rehydration process, including the type of drying method used, the initial water content of the apricots, and drying temperature. Results showed that increasing the drying temperature from 60 °C to 80 °C resulted in a decrease in the rehydration capacity (Table 2). This decrease is due to the higher temperature causing more damage to the cell walls, making it more difficult for water reabsorption. Even though drying at 60 °C has preserved the apricots structural integrity. But the treatment took a lot of

time (22 h) and consumed energy. All samples were treated with anti-browning agents such as Na₂S₂O₅ and KHSO₃. Had an average rehydration percentage of more than 50%, especially in higher concentration of 5% compared to low concentration (2% to 0.5%) for both agents used. This result means that dried apricots structural integrity is conserved, and water can be absorbed until reaching almost the original properties [38].

Impact of drying temperature on TPC and β-carotene content

Figure 4a and 4b presents the effects of different drying temperatures on the phenolic compounds and β-carotene content of dried apricot samples (We ensured consistent conditions (5% of Na₂S₂O₅ and relative humidity of 30%) while varying only the temperature to achieve a reliable comparison). The results show that both TPC and β-carotene content were significantly influenced by temperature (p<0.05), with the highest TPC (486.67 ± 5.86 mg AGE/100 g DW) and β-carotene content (2473.38 ± 20.49 μg/100 g DW) being obtained from samples treated at 80 °C, followed by those treated at 70 °C (Figure 4a and 4b). The TPC of fresh apricots from Midelt (Mibladen) region was found to be much higher (636.67 ± 21.01 mg AGE/100 g DW) than that of the dried samples, with a decrease of 23.56% observed after drying at 80 °C. These findings are consistent with previous studies [39-41] that have also shown that a short drying time caused by high temperature can reduce oxidation and degradation of TPC



(Figure 4a). In contrast to the TPC, the β -carotene content showed (Figure 4b) a more significant loss during drying, with a 47.93% decrease observed at 60 °C compared to 80 °C under similar drying conditions. This loss is due to β -carotene's exposure to oxygen and a longer drying time which can lead to degradation [34]. Similar results have been reported in previous studies where drying apricots using microwave or hot air convection at 60 °C and 70 °C resulted in a 50% and 40% loss of β -carotene respectively [42]. Furthermore, we found that a 5-min blanching treatment improved the stability of carotenoids for different drying temperatures. This enhancement could be attributed to the protein denaturation and matrix structure disruption caused by thermal blanching, which enhances the ability to extract β -carotene [19, 43]. Based on the results presented above, we can confidently conclude that

the optimal conditions for achieving the best drying time, color preservation, and retention of phenolic compounds and beta-carotenoids are as follows: 5 min of blanching, 80 °C drying temperature, and 30% relative humidity for both anti-browning agent concentration. Consequently, we refer to these conditions as the "optimal conditions". Moving forward, it is essential to investigate the impact of agent concentration under these optimal conditions to ensure that the apricots meet international quality standards.

Impact of anti-browning agent concentration on color, browning rate, HMF, TPC, and residual SO₂ content

Anti-browning agents such as Na₂S₂O₅ and KHSO₃ are commonly used in the food industry to inhibit enzymatic browning and preserve the color of fruit and vegetables. In the context of apricots, the use of these agents can help to maintain the natural color of apricots during the drying process. Table 3 presents the impact of anti-browning agent concentration under optimum conditions, on the color measurement of different apricot samples. The agent's concentrations had a significant effect on both E* (intensity of color change) and chromaticity C*. The use of anti-browning agents (Na₂S₂O₅ and KHSO₃) at concentration 0.5%, 1%, 2%, and 5% resulted in better color retention compared to the control (Table 3). Increasing the concentration of both anti-browning agents (Na₂S₂O₅ and KHSO₃) reduced apricots color degradation (increase of chromaticity C*). These results can be explained by the fact that a higher concentration of sulphites solution preserves more orange color through direct enzymatic inac-

Table 3: Effect of anti-browning agent concentration on quality attributes of dried apricots under optimum conditions (Blanching = 5 min; temperature = 80 °C; and relative humidity = 30%).

Anti-browning agent		Chromatic characteristic			Biochemical characteristic				
Agent	Concentration	E*	C*	% Browning	HMF	TPC (mg AGE/100 g)	β -carotene (µg/100 g)	SO ₂ (mg de SO ₂ /kg DF)	PPO inhibition rate (%)
Control	0%	36.50 ± 5.65 ^a	26.88 ± 5.78 ^a	39.68 ± 4.93 ^a	77.12 ± 0.67 ^a	346.67 ± 3.51 ^a	468.29 ± 15.97 ^d	00.00 ± 0.00 ^a	97.30 ± 0.09 ^a
Na ₂ S ₂ O ₅	0.5%	21.25 ± 0.88 ^b	44.43 ± 1.26 ^b	24.16 ± 4.88 ^{b,c}	33.24 ± 0.44 ^b	362.67 ± 3.79 ^b	454.93 ± 10.99 ^d	38.57 ± 2.24 ^b	97.72 ± 0.93 ^{a,b}
	1%	20.06 ± 2.57 ^b	44.74 ± 2.72 ^b	24.84 ± 1.96 ^{b,c}	28.71 ± 0.82 ^c	384.33 ± 5.13 ^c	424.77 ± 19.70 ^e	88.53 ± 2.24 ^c	98.10 ± 0.18 ^b
	2%	18.26 ± 1.50 ^b	46.92 ± 0.84 ^b	22.16 ± 1.42 ^{b,c}	20.73 ± 0.98 ^d	406 ± 3.61 ^d	1929.94 21.08 ^e	185.82 4.95 ^c	97.96 ± 0.24 ^{a,b}
	5%	15.25 ± 1.19 ^b	53.66 ± 0.97 ^c	19.6 ± 1.38 ^b	10.79 ± 0.77 ^e	486.67 ± 5.86 ^e	2473.38 20.49 ^b	582.81 16.04 ^f	99.42 ± 0.41 ^c
KHSO ₃	0.5%	22.18 ± 0.49 ^b	44.43 ± 1.26 ^b	29.5 ± 0.81 ^c	35.03 ± 0.50 ^b	345.67 ± 7.37 ^a	266.89 ± 7.38 ^a	46.94 ± 6.09 ^b	97.38 ± 0.36 ^{a,b}
	1%	21.04 ± 1.26 ^b	47.65 ± 2.6 ^b	22.44 ± 2.05 ^{b,c}	30.87 ± 0.72 ^c	378 ± 2.65 ^c	315.16 ± 6.11 ^b	104.58 ± 3.83 ^d	98.02 ± 0.84 ^b
	2%	18.84 ± 2.71 ^b	45.38 ± 1.23 ^b	22.1 ± 2.7 ^{b,c}	29.90 ± 0.81 ^d	407.67 ± 1.53 ^d	713.73 ± 11.54 ^e	203.22 ± 4.69 ^f	97.96 ± 0.34 ^{a,b}
	5%	17.37 ± 1.89 ^b	52.85 ± 0.67 ^c	21.95 ± 1.93 ^{b,c}	16.52 ± 0.53 ^e	481 ± 1.00 ^e	1617.77 ± 9.74 ^f	621.29 ± 8.54 ^h	99.45 ± 0.34 ^c
Sig Agent		n.s	n.s	n.s	***	**	***	***	***
Sig Concentration		*	***	**	***	***	***	***	***
Sig Agent*concentration		n.s	n.s	n.s	***	**	***	**	**

Note: E*: Color intensity change; C*: Chromaticity; TPC: Total phenol content; HMF: Hydroxymethyl-furfural; SO₂: Sulfur dioxide content; PPO: Polyphenol oxidase; Signification levels: *p < 0.05; **p < 0.01; ***p < 0.001; n.s = non-significant p > 0.05; Column with the same letter belong to the same group.

Table 4: Correlation coefficients between quality indicator of apricot under optimum conditions (Blanching = 5 min; Temperature = 80 °C; and relative humidity = 30%).

	R*(E*)	R*(C*)	R*(% Browning)	R*(HMF)	R*(TPC)	R*(β-carotene)	R*(SO ₂)	R*(PPO)
R*(E*)	1	-0.777	0.740	0.887	-0.852	-0.578	-0.844	-0.705
R*(C*)	-	1	-0.733	-0.870	0.805	0.429	0.848	0.640
R*(% Browning)	-	-	1	0.791	-0.800	-0.461	-0.783	-0.681
R*(HMF)	-	-	-	1	-0.931	-0.627	-0.912	-0.800
R*(TPC)	-	-	-	-	1	0.711	0.912	0.751
R*(β-carotene)	-	-	-	-	-	1	0.562	0.519
R*(SO ₂)	-	-	-	-	-	-	1	0.760
R*(PPO)	-	-	-	-	-	-	-	1

Note: Correlation coefficients average; E*: Color intensity change; C*: Chromaticity; TPC: Total phenol content; HMF: Hydroxymethyl-furfural; SO₂: Sulfur dioxide content; and PPO: Polyphenol oxidase.

tivation of PPO, which occurs due to a modification of the tertiary structure of the PPO enzymes caused by the reduction of disulfide bond [44]. For low concentrations, the action is mainly manifested by the reduction of quinones, leading to the regeneration of parental phenols [45].

The residual SO₂ content of various samples was analyzed to ensure that dried apricots contained a quantity (ranging from 38.57 to 621 mg of SO₂/1000 g), adhered to the limit established by the Codex Alimentarius (maximum :2000mg/1000g) [36]. No samples contained extreme levels of SO₂. The concentration of residual SO₂, HMF, Browning rate, TPC, chromatic characteristics, and PPO activities were closely correlated. As indicated in Table 3, an increase in concentration of anti-browning agents (Na₂S₂O₅ or KHSO₃) resulted in a significant (p < 0.05) increase in C*, TPC, β-carotene content, and residual SO₂. The best preservation of these parameters was observed with the use of Na₂S₂O₅. In contrast, an increase in concentration of anti-browning agents led to a significant (p < 0.05) decrease in E*, % Browning, HMF, and PPO activities. The better inhibition of these indicators of apricot alteration was achieved with the use of Na₂S₂O₅. Regarding the preservation of β-carotene content, it's noteworthy that Na₂S₂O₅ outperformed KHSO₃, even when the residual SO₂ levels were nearly identical. This difference in effectiveness may be attributed to variations in chemical reactivity, the release kinetics of SO₂, and the higher solubility of Na₂S₂O₅ in water. Additionally, in accordance with the theoretical sulfur dioxide yield specified in Commission Regulation (EU) No 231/2012 [46], sodium metabisulfite exhibited a significantly higher yield (67.4% of SO₂) compared to potassium bisulfite (53.5% of SO₂). According to statistical analyses (Table 4), the strong correlation between HMF with browning rate (0.80) and SO₂ content (-0.91) was also observed. This suggests that these parameters are interrelated and can influence each other during the drying and storage of apricots. The effectiveness of Na₂S₂O₅ and KHSO₃ in controlling non-enzymatic browning can be explained by their ability to act on different pathways and stages of this set of reactions. Sulfites react with carbonyl compounds to form hydroxysulfonates, blocking the appearance of brown products [47]. This explains why higher browning values were observed in control samples compared to treated samples, and lower HMF was observed at higher concentrations of Na₂S₂O₅ and KHSO₃. Furthermore, the

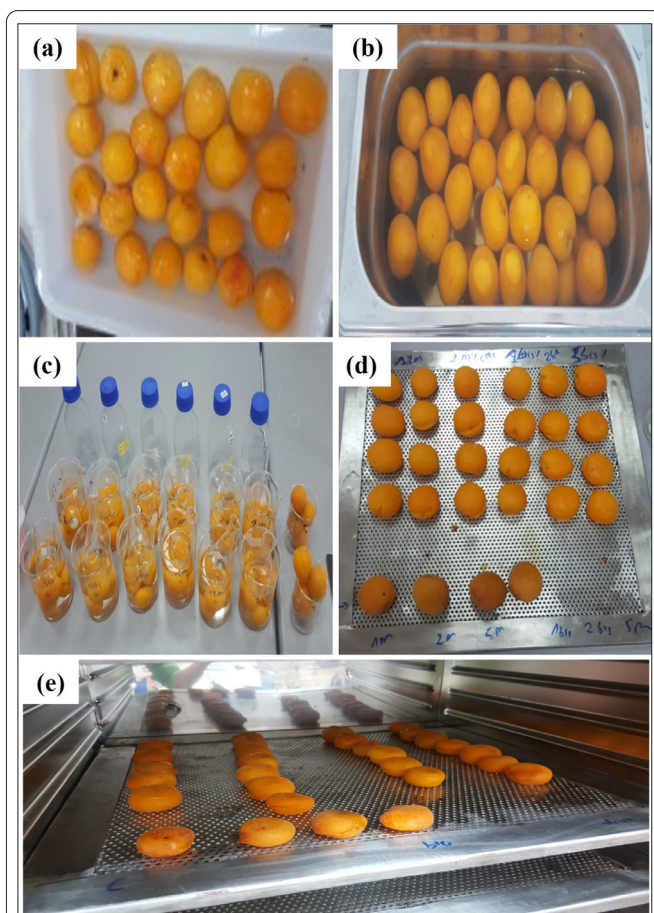
inhibition of PPO activity by anti-browning agents indicated that PPO inhibition increased with increasing agent concentration, with the maximum PPO inactivation recorded at 5% concentration for both agents. Slight amounts of HMF (10.79 mg/100 g) and browning rate (19.6 ± 1.38%) were detected. Thus, it can be concluded that browning is primarily caused by non-enzymatic browning (Maillard Reaction) at higher concentrations of anti-browning agents. TPC is closely correlated (Table 4) with E* (-0.85), C* (+0.80), browning rate (-0.80), and SO₂ content (0.91). Higher browning rates and increased E* values corresponded to more TPC degradation because polyphenols are the substrate of PPO enzymes responsible for enzymatic browning. By reducing browning, TPC and color level can be better preserved. Therefore, the highest amount of TPC was recorded at optimum drying conditions with 5% Na₂S₂O₅.

Conclusion

Preserving apricots presents a formidable challenge due to their limited shelf life and susceptibility to spoilage. While drying is a commonly employed technique in the agri-food industry, the lack of precise control during the drying process can lead to undesirable outcomes, such as damaged apricots. This study, however, illuminates a promising solution. By employing optimized conditions, including a blanching period of 5 minutes and drying at 80°C with 30% relative humidity, in conjunction with an appropriate concentration of an anti-browning agent at 5% Sodium Metabisulfite concentration, we achieved notable improvements in preserving the appearance and quality of Canino variety apricots. These conditions not only reduced the drying time but also enhanced the preservation of essential parameters such as Total Phenols Content, β-carotene levels, and color, all while adhering to international standards for SO₂ content. Furthermore, this study enabled a reduction in the quantity of sulfur derivatives without compromising the vibrant orange color characteristic of the Canino variety sourced from the Midelt (Mibladen) region of Morocco.

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Appendix 1: Different steps for drying apricots Var. Canino described in the manuscript: (a) Cleaning; (b) Blanching at 90 °C for a specified duration (1 min; or 5 min); (c) Soaking in anti-browning agent; (d) Preparation before drying; and (e) Drying process at a fixed condition.



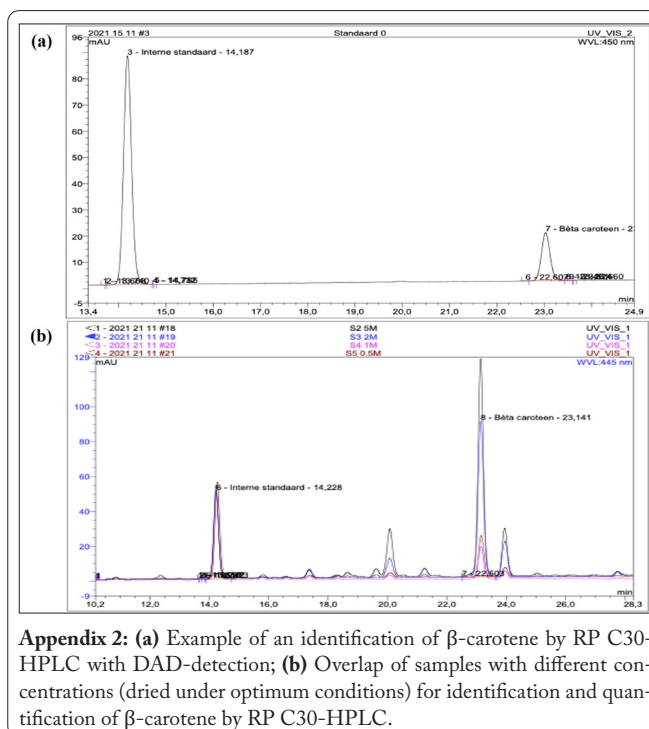
Appendix 4: Dried apricots under optimum conditions (Blanching = 5 min; temperature = 80 °C; relative humidity = 30%) using two anti-browning agents ($\text{Na}_2\text{S}_2\text{O}_5$ and KHSO_3) at different concentrations from 0.5% to 5%.

Conflict of Interest

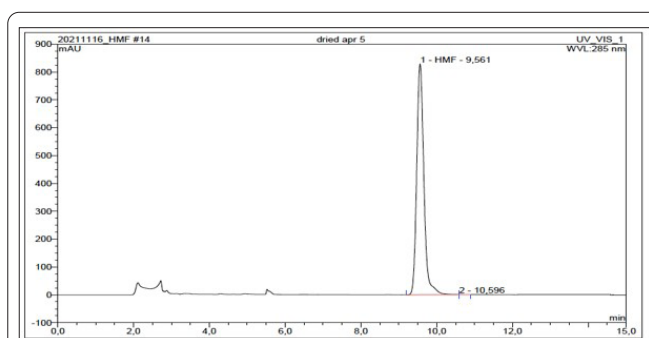
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 2: (a) Example of an identification of β -carotene by RP C30-HPLC with DAD-detection; (b) Overlap of samples with different concentrations (dried under optimum conditions) for identification and quantification of β -carotene by RP C30-HPLC.



Appendix 3: Example of an identification of HMF by HPLC ultimate 3000 equipped with a column Lichrosorb RP18-5 (250 x 4.6 mm, 5 μm).

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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