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ORIGINAL ARTICLE

Reducing atmosphere drying as a novel drying technique for preserving the sensorial and nutritional notes of foods

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Abstract Reducing atmosphere drying (RAD) was assayed as a novel technique for preserving the color and the nutritional fresh notes of apricot. A freeze, hot air and vacuum drying techniques were applied for a comparison purpose. The results showed that the apricot samples dried by both RAD_{MIX} and $RAD_{NITROGEN}$ preserved better the fresh color notes while the freeze-drying was characterized by light and dully notes compared to a fresh sample. The total phenolic content significantly differed between fresh, RAD_{MIX}, RAD_{AIR}, hot air and vacuum with the highest value observed for both vacuum and hot air with 284.8 and 259.5 mg GAE 100 g^{-1} dm, respectively. DPPH inhibition activity was significantly similar for both fresh (or freeze drying) and each RAD_{MIX}, hot air and vacuum dried samples with 83.52, 76.3, 70.31, 67.86%, respectively, with the highest value attributed to RAD_{MIX} sample. The RAD-type dried samples (RAD_{MIX}, $RAD_{NITROGEN}$, RAD_{AIR}) possessed ABTS scavenging activity range of 68.74, 64.49 and 61.61 µmol TE g^{-1} dm respectively, which were close to that of the fresh sample (63.36 µmol TE g^{-1} dm) with the highest value attributed to RAD_{MIX} sample. The total flavonoid content was significantly similar between fresh (or freeze drying), vacuum, hot air and RAD_{MIX} samples with a range of 27.38, 24.25, 19.41 and 18.81 mg QE 100 g^{-1} dm, respectively, which exhibited an advantageous role of hydrogen in RAD_{MIX} system over both $RAD_{NITROGEN}$ and RAD_{AIR}. For the first time, a technique based on the use of hydrogen in the drying atmosphere of a closed system was successfully proved for drying foods. This novel technique exhibits an opportunity for the food drying processors to produce dried foodstuffs with fresh color and nutritional notes.

Keywords Reducing atmosphere drying · Apricot · Color · Antioxidant capacity · Fresh notes

Introduction

Drying is one of the oldest, cheapest and most common food preservation techniques used to extend the shelf life of various foodstuffs such as fruits, vegetables, meat, grains and plants, and make them available out of season. Although the use of several drying techniques such as sun, hot air, osmotic, microwave, vacuum, heat pump, and freeze drying as well as their combinations by food industries; the convective drying is the most common technique because of its simplicity and low cost (Wojdyło et al. 2009; Megías-Pérez et al. 2014; Chong et al. 2013). However, in many conventional drying methods as the connective one, the product is exposed to at least one critical factor such as high temperatures and oxygen-contained atmosphere, which introduce negative alteration to many heat- and oxygen- sensitive components (O'Neill et al. 1998; Santos and Silva 2009). These undesirable modifications of heat- and oxygen-sensitive components could be categorized in two essential types: the sensorial modification expressed by the loss of the fresh color, flavor and aroma, and the nutritional modification presented by the loss of the nutritional properties of some bioactive compounds such as vitamins, polyphenols and unsaturated fatty acid. The oxygen present in drying atmosphere possesses the ability to promote the chemical and enzymatic

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reactions in foods and then affect the overall quality by changing the color, taste, texture and nutritional properties of foods (Liu et al. 2014). The oxidative enzymatic browning mediated by polyphenol oxidase (PPO) is considered as the principal factor in developing undesirable brown color in fruit products. In industry, this undesirable browning phenomenon is controlled by the use of some chemicals such as ascorbate, sodium bisulfite, sulfur dioxide and organic acids (citric, malic and acetic acid). The use of sulfite compounds is more common in the drying process of some fruits especially apricot and grape. Otherwise, it has been reported that these sulfite compounds may cause many health problems such as hypersensitivity in some individuals (Hall 2007).

The undesirable oxidation reactions occurred during the drying process have to be minimized to preserve the nutritional and sensorial values of foods; this goal can be achieved with a process performed under as low as possible oxygen condition. In this context; the air used in conventional methods as a drying atmosphere could be replaced with some gases such as nitrogen (N_2), argon (Ar) or carbon dioxide (CO_2) to exclude oxygen implicated in the deteriorative reactions (Mujumdar and Law 2010). In this regard, the heat pump drying (HPD) technique has been successfully tested in many different types of food (Chong and Law 2010). The HPD minimizes losses in color and improves rehydration capacity, texture and other important quality parameters (Hawlader et al. 2006; Liu et al. 2014). The studies of HDP technique carried out with modified gaseous conditions were generally limited to modify the ambient atmosphere with CO_2, N_2 or their combinations. There was any study that assayed the use of hydrogen in gaseous combinations as a drying atmosphere.

In the drying industry, some fruits like apricot and grape are treated with reducing chemicals such as the sulfite compounds to provide a desirable golden color to the product as well as biological stability during food storage. However, the use of sulfite compounds was restricted by many countries due to its harmful effects on the health of consumers. The idea of the present study was to use an alternative compound possessing similar reducing property as the sulfite compounds but without residues in the product or negative effects on the health of the consumer, that is the hydrogen.

In this study, a new drying technique called Reducing Atmosphere Drying (RAD) that based on the use of gaseous combinations (CO_2 and N_2) containing reducing gas (H_2) in a closed-system was investigated for the first time for drying foods in laboratory conditions. Reducing Atmosphere term was used in this study to describe the use of a gaseous mixture containing hydrogen gas. Apricot was taken as a sample and dried by freeze-, hot air and vacuum drying beside the RAD technique for a comparison purpose. The color parameters and antioxidant capacity (DPPH, ABTS, flavonoids, total phenolics) of the dried samples were investigated as quality determinants of dried products. The aim of this new drying method is to obtain a dried product with high sensorial and nutritional quality by benefiting from advantages of reducing property of hydrogen as an alternative to the commonly used chemical preservatives in apricot drying processing i.e. sulfite compounds.

Materials and methods

Fruit sample

Hacıhaliloglu apricot variety (*Prunus armeniaca* L.) fruits were obtained from Malatya region in Turkey during June 2017 and stored at 4 °C until use. Before the drying process, the fruits were washed by the tap water; inedible parts were discarded and fruit halves were sliced into 8 × 8 mm cubes.

Chemicals

2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,2'-azinobis (3-ethyl-benzothiazoline-6-sulphonate) (ABTS), Folin–Ciocalteu's, Methanol, Ethanol, Hydrochloric acid, Potassium persulphate, Sodium acetate, Sodium carbonate, Ascorbic acid, Trolox, and Gallic acid are from analytical grade and purchased from Sigma Aldrich.

Approximate composition of fresh fruit

The moisture content of the apricot fruits (5 g ± 0.1 mg) was determined by drying in an oven at 105 °C under atmospheric pressure until constant weight and expressed as weight in 100 g dry matter. The multiparameter analyzer (Consort, C3040, Belgium) was used to measure the pH with a pH electrode (Consort, SP10B, Belgium). The total soluble solids (°Brix) were determined by using a refractometer (Boeco Digital Abbe Refractometer, BOE 32400, Germany).

Drying experiment

Apricot samples were dried in different drying systems including laboratory-type Reducing Atmosphere Drying System prototype designed in RCRAF (Research Center for Redox Applications in Foods), freeze-, vacuum and hot air drying to reach a final humidity value below 20%. In the RAD system, three different drying atmospheres were evaluated: Air, 100% N_2 and hydrogen included- gaseous mixture (4% H_2, 5% CO_2, 91% N_2).

Reducing atmosphere drying assay

The Reducing Atmosphere Drying System was designed and constructed under laboratory conditions in the Research Center for Redox Applications in Foods (RCRAF) (Fig. 1).

The RAD system functions as follows: the gas mixer instrument regulates the combination composition of gases at desired proportions. The gaseous mixture exits the gas mixer to reach the drying closed-cycle. The blower pushes the gaseous mixture toward the heater. The heated- gaseous mixture (in this assay 70 °C) is then passed into the drying cabinet which benefits from heat and light isolation system and contains a fruit sample deposited on a perforated drying tray inside. The wet gaseous mixture leaves the drying cabinet to reach the gradual condenser system (− 20 °C) which separate the moisture from the gaseous atmosphere. The dry gaseous mixture reaches the blower again to start a new cycle. Since the system is a closed loop, the gaseous mixture is continuously circulated and a fresh gaseous mixture is introduced at certain time intervals. The hydrogen content of the gaseous mixture was controlled periodically.

Freeze drying assay

The apricot samples were firstly kept in the freezer at − 80 °C for approximately 8 h and then allowed to dry in the freeze- dryer (Martin Christ, Alpha 1-2 LD, Germany) for 22 h. The freeze-dried sample was evaluated as a fresh and control sample.

Vacuum drying assay

The apricot samples were placed in a vacuum dryer (Daihan, WOV-30, Korea) and dried at 70 °C for 6 h.

Hot air drying assay

The apricot samples were placed in an oven (Memmert, UN55, Germany) at 70 °C for 7 h.

Color measurement

The CIE color parameters (L*, a* and b*) of the samples were measured by using a colorimeter (Minolta, CR 410, Osaka, Japan) according to Ihns et al. (2011) and the device was calibrated before each measurement against a standard white surface. The CIE L*, a* and b* values represent

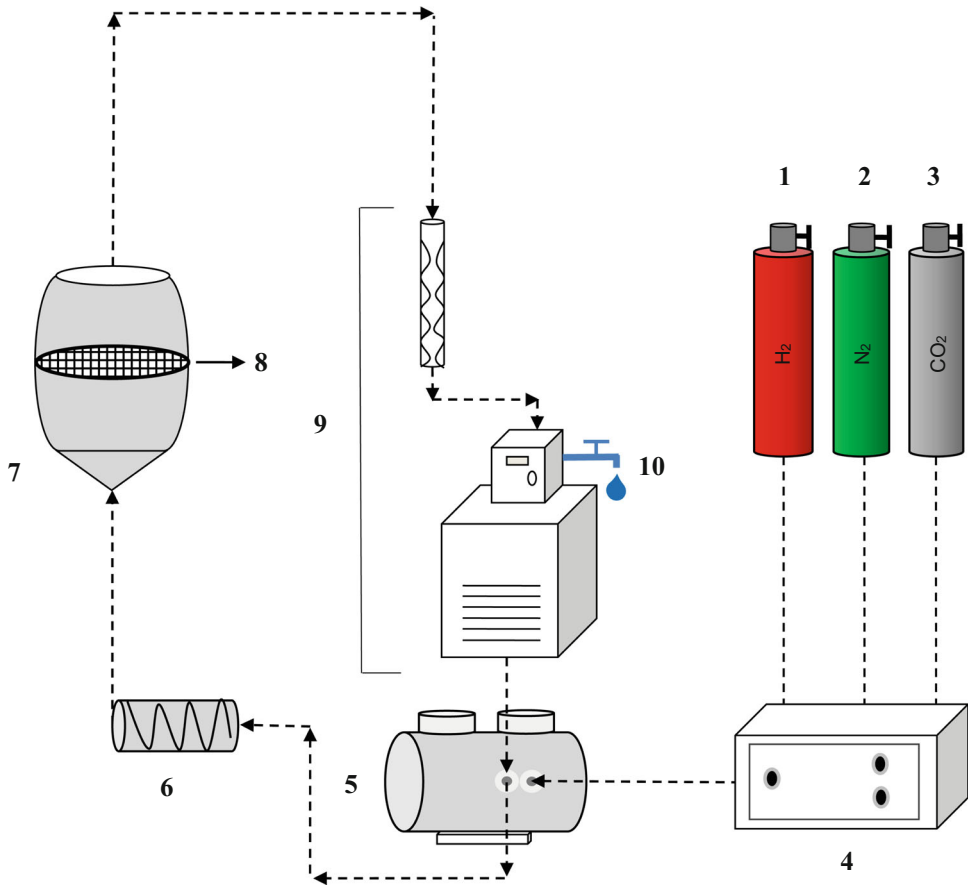


Fig. 1 Schematic diagram of the reducing atmosphere drying system. 1 hydrogen cylinder; 2 nitrogen cylinder; 3 carbon dioxide cylinder; 4 gas mixer; 5 gas blower; 6 heater; 7 drying cabinet; 8 drying tray; 9 gradual condenser system; 10 separated-moisture

respectively; the dark–light spectrum, the green–red spectrum and the blue–yellow spectrum. The total color changes (ΔE) based on the difference of L*, a*, b* between fresh (f) and dried samples (d) were calculated from the following equation:

$$\Delta E = \left[\left(L_f^* - L_d^*\right)^2 + \left(a_f^* - a_d^*\right)^2 + \left(b_f^* - b_d^*\right)^2 \right]^{1/2}$$

Sample extraction

The sample extraction was performed using the method proposed by Vijaya Kumar Reddy et al. (2010) with slight modifications. A weight of 0.2 g of fruit sample was taken for DPPH, ABTS and total phenolic assays, while 1 g of fruit sample was considered for the total flavonoid content; then 10 ml of 50% methanol (v/v) containing 0.1% HCl was added and homogenized at 1300 rpm for1 min (IKA Ultra Turrax, T18 model, Korea). The homogenate was kept in the dark for 2 h at 25 °C and then centrifuged at 10,000 ×g (10 °C for 15 min). The supernatant was filtered through a Whatman No. 4 filter and then through 0.45 µm filter. The filtrate was either used immediately or left to further analysis at − 80 °C.

DPPH (1,1-diphenyl-2-picrylhydrazyl) free radical scavenging activity assay

The DPPH scavenging activity was determined according to Madrau et al. (2009) with slight modifications. 500 µl of sample extract was mixed with 2.5 ml of a 6×10^{-5} M methanol solution of DPPH. The reaction mixture was incubated in the dark at room temperature for 90 min and then the absorbance was measured by spectrophotometry at 515 nm (Thermo Scientific, AQ 8000, USA). The DPPH inhibition value was calculated according to the following equation:

$$\text{DPPH } (\%) = \left[1 - \frac{\mathbf{Abs}_{sample}}{\mathbf{Abs}_{control}}\right] \times 100$$

ABTS [2,2'-Azinobis (3-Ethylbenzothiazoline-6-Sulphonic Acid)] free radical scavenging activity assay

The ABTS scavenging activity was performed using the method proposed by Ozgen et al. (2006) with slight modifications. 7 mM ABTS stock solution with 2.45 mM potassium persulfate ($K_2S_2O_8$) was prepared by using 20 mM sodium acetate buffer (pH 4.5) and then incubated in the dark at room temperature for 12–16 h for the formation of radical. Prior to measurement, the ABTS solution was diluted with 20 mM acidified sodium acetate ($C_2H_3NaO_2$) to an absorbance of 0.700 ± 0.01 at 734 nm. Next, 100 µl of sample extract was mixed with 2.9 ml of ABTS solution and then allowed to incubation period at room temperature for 6 min. The absorbance of the mixture was then measured at 734 nm by a spectrophotometer (Thermo Scientific, AQ 8000, USA). The ABTS inhibition value was calculated according to the following equation:

$$\text{ABTS } (\%) = \left[1 - \frac{\mathbf{Abs}_{sample}}{\mathbf{Abs}_{control}}\right] \times 100$$

A Trolox calibration curve was fitted for a concentration range of 0–2.5 mM (y = 35.854x, R^2 = 0.995). The ABTS scavenging activity results were expressed as µmol Trolox equivalents (TE) per gram dry matter of sample.

Total phenolic content assay

The total phenolic content was determined by using Folin–Ciocalteu's method according to López et al. (2010). 0.5 ml of the sample extract was mixed with 0.5 ml of Folin–Ciocalteu's reagent and vortexed. After incubation for 5 min at room temperature, 2 ml of 20% sodium carbonate (Na_2CO_3) solution was added and vortexed again. After 30 min of incubation in the dark, 10 ml of ultrapure water was added, vortexed and centrifuged (4000 × g for 5 min at room temperature). The supernatant was taken up in the cuvette and the absorbance was read at 765 nm with a spectrophotometer (Thermo Scientific, AQ 8000, USA). Gallic acid was used as standard for a concentration range of 0–100 µg ml^{-1} (y = 5.0255x, R^2 = 0.9956). The total phenolic content results were expressed as mg gallic acid equivalent (mg GAE) per 100 g dry matter of sample.

Total flavonoid content assay

The total flavonoid content assay was performed according to the method proposed by Vital et al. (2017). 300 µl sample extract was mixed with 150 µl $AlCl_3$ solution and 2550 µl methanol. After incubation for 30 min at room temperature, the absorbance of the sample was read at 425 nm with a spectrophotometer (Thermo Scientific, AQ 8000, USA). Quercetin was used as standard for a concentration range of 0–300 µg ml^{-1} (y = 7.2365x, R^2 = 9973). The total flavonoid content results were expressed as mg quercetin equivalent (QE) per 100 g dry matter of sample.

Statistical analysis

The data were expressed as mean ± SD (standard deviation) and the ANOVA analysis was carried out with one-way analysis of variance by using Minitab 17 program.

Results and discussion

Approximate composition

The average moisture, pH and total soluble solids (Brix) values of the fresh Hacıhaliloglu apricot variety were determined as 74.77%, 5.66 and 22.95 °B, respectively. Similarly, a moisture content value of 75.22% and Brix of 23.20 were observed by Akin et al. (2008) for the same variety.

Color parameters

The color changes of the dried apricot samples were measured by considering CIE L*, a*, b* values and total color change (ΔE)(Table 1). These values are the most common color coordinates used to determine the visual characteristics of fruits and vegetables (García-Alonso et al. 2004).

Despite the similarity in a* values of the different drying processes ($p < 0.05$), the L* and b* values present a significant effect on the color change. The b* data were grouped in two categories: (1) RAD-type techniques besides the freeze-drying and (2) vacuum and hot air drying, with a significant difference between them on one side, and between them and the fresh simple on the other side($p < 0.05$). The minimum total color change (ΔE) was observed for $RAD_{NITROGEN}$ and RAD_{MIX}, while the maximum ΔE was noted for each vacuum drying, hot air and RAD_{AIR}.

The change in color is generally associated with enzymatic/non-enzymatic reactions as well as a pigment loss in fruits and vegetables. The decrease in L* value reflects the darkening of the apricot samples while an increase in a* value is related to a browning phenomenon in fruits and vegetables (Akin et al. 2008; García-Martínez et al. 2013).

L* and a* values of the fresh apricot samples in the present study were similar to the values obtained by Akin et al. (2008) in the Hacihaliloglu variety but b* value was found to be higher. The highest and lowest L* value was found for the freeze-dried and vacuum-dried samples (Table 1). For all drying treatments, the b* value of the samples significantly decreased ($p < 0.05$). The highest browning phenomena were found for the vacuum-dried samples with the lowest L* and b* values, while the freeze-dried sample showed L* value higher than fresh, which induces lightning (bleaching) effect of the samples (Table 1). This phenomenon was generally explained by the increase in the L* value and/or the decrease in chroma value. The same phenomenon was observed for freeze-dried pumpkin where the chroma value decreased and the freeze-dried product was characterized by more light and pale color notes compared to the fresh sample (Guiné and Barroca 2012). These undesirable modifications of the fresh color notes of food product present advantage of the RAD technique over the freeze drying.

When all the L*, a* and b* parameters beside ΔE values are taken into account, the closest color values to the fresh sample were noted for the apricot samples dried by RAD_{MIX} and $RAD_{NITROGEN}$ (Table 1). Similarly; Alwazeer (2018) observed that RAD_{MIX} method is the best drying method for preserving the color of Şalak apricot variety.

Antioxidant capacity

Total phenolic content

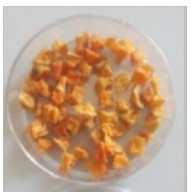
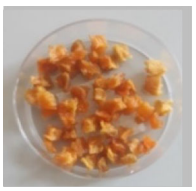
The phenolic compounds are well-known as plant secondary metabolites and play not only the role of free radical scavenger but also it possesses multiple medicinal and physiological functions (Sultana et al. 2012). In the literature, the total phenolic content in fruits and vegetables was generally carried out using Folin–Ciocalteu's method and this method has been used for many years to determine the total phenolic content (TPC) in natural matrices. Since Folin–Ciocalteu's method based on the mechanism of oxidation/reduction reaction, it was considered as an antioxidant method too (Kamiloglu et al. 2014).

While $RAD_{NITROGEN}$ showed the lowest TPC, the higher TPC value was observed for the vacuum and hot air dried samples (Fig. 2). It is also suggested that the phenolic compounds, which have a high large molecular weight and are bound to the plant cell wall, may cause an increase in the total phenolic content through the effect of temperature (Sultana et al. 2012). Hence, this phenomenon could explain the high level of total phenolic content observed for the vacuum, hot air and RAD_{AIR} drying methods, which possess favorable conditions for the oxidation of polyphenols. Despite all this, there is no certain information about the effect of drying on the phenolic content of apricot in the literature (Madrau et al. 2009).

DPPH scavenging activity

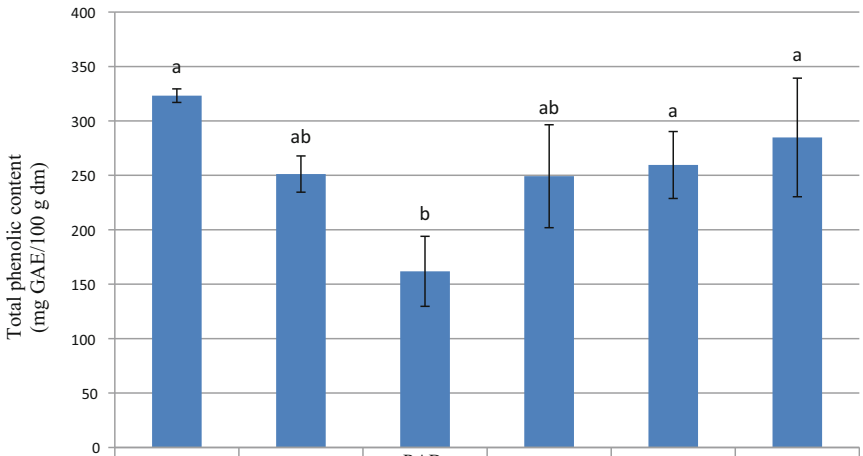
The results of DPPH show the non-significant difference between RAD_{MIX}, hot air and vacuum dried samples, with the highest value attributed to RAD_{MIX} (Fig. 3). The three latter drying techniques show similarity in DPPH results compared with a fresh sample that presents at the same time the freeze-drying simple (83.52%)($p < 0.05$). While the high antioxidant activity of the hot air and vacuum dried samples could be attributed to the formation of heat-induced antioxidants such as MRPs (Manzocco et al. 2000), the high antioxidant activity of the RAD_{MIX} could

Table 1 Color parameters of the fresh and freeze-, RAD_{MIX}, $RAD_{NITROGEN}$, RAD_{AIR}, hot air and vacuum dried of Hacihaliloglu apricot variety

Samples	Color parameters			
	L*	a*	b*	ΔE*
 **Fresh**	61.119 ± 2.690[b]	10.038 ± 2.834[b]	49.536 ± 2.152[a]	–
 **Freeze Drying**	68.547 ± 0.553[a]	8.057 ± 0.214[b]	40.993 ± 1.175[bcd]	11.49
 **RAD_{MIX}**	55.320 ± 1.359[c]	12.643 ± 0.846[ab]	42.123 ± 0.936[bc]	9.76
 **$RAD_{NITROGEN}$**	56.36 ± 1.85[bc]	10.820 ± 0.877[ab]	43.81 ± 2.38[b]	7.48
 **RAD_{AIR}**	51.707 ± 0.0462 [cd]	14.463 ± 0.271[a]	40.05 ± 0.0520[bcd]	14.00
 **Hot Air Drying**	52.51 ± 3.68 [cd]	12.005 ± 0.432[ab]	38.565 ± 1.453 [cd]	14.08
 **Vacuum Drying**	48.72 ± 2.07[d]	13.223 ± 0.543[ab]	37.00 ± 2.20[d]	17.91

Different letters (a, b and c) in the same column indicate statistically significant difference ($p < 0.05$)
RAD_{MIX}: 4% H_2, 5% CO_2, 91% N_2; $RAD_{NITROGEN}$: 100% N_2; RAD_{AIR}: Air, (n = 3)

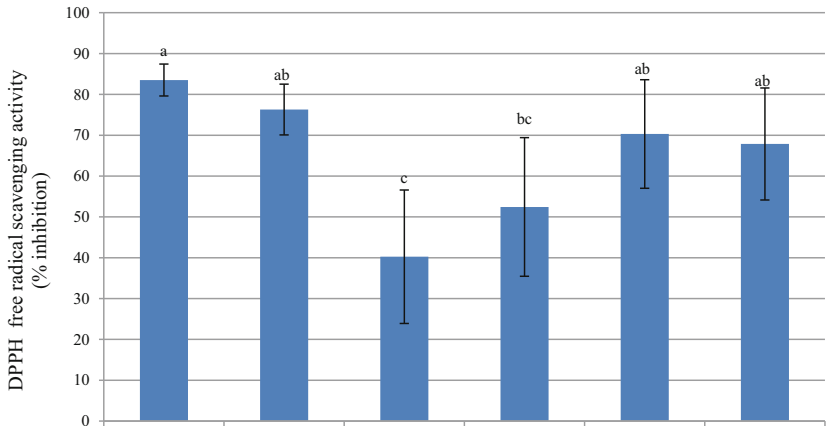
be linked to the reducing property of H_2 gas that protects the oxygen-sensible substances found in products such as the bioactive compounds from the destructive oxidative reactions happened in the presence of oxygen. This role of hydrogen likes that attributed to ascorbic acid, for example, where it is used in food industry as an anti-browning agent. As mentioned above, the high antioxidant content of the hot air and vacuum dried samples was related to the



	Fresh	RAD MIX	RAD NITROGEN	RAD AIR	Hot air	Vacuum
mg GAE/100g (dm)	323.19	251.17	161.8	249.2	259.50	284.8

Fig. 2 Total phenolic content of dried and fresh samples of Hacihaliloglu apricot variety

Different letters (a, b and c) indicate statistically significant difference ($p<0.05$). RAD_{MIX} : 4% H_2, 5% CO_2, 91% N_2; $RAD_{NITROGEN}$: 100% N_2; RAD_{AIR}: Air, (n=3); dm: dry matter; GAE: Gallic acid equivalent



	Fresh	RAD MIX	RAD NITROGEN	RAD AIR	Hot air	Vacuum
DPPH INHIBITION (%)	83.52	76.3	40.25	52.43	70.31	67.86

Fig. 3 DPPH inhibition activity of dried and fresh samples of Hacihaliloglu apricot variety

Different letters (a, b and c) indicate statistically significant difference ($p<0.05$). RAD_{MIX} : 4% H_2, 5% CO_2, 91% N_2; $RAD_{NITROGEN}$: 100% N_2; RAD_{AIR}: air; (n=3); dm: dry matter

formation of stable intermediate products with high antioxidant activity property during the oxidation step of polyphenols as well as the formation of non-enzymatic browning compounds i.e. melanoidins (Albanese et al. 2013). The melanoidins, which are high molecular weight heterogeneous polymers that occur in the final stage of the Maillard reaction, possess various functional properties such as antioxidants, antihypertensive and metal binders (Cossu et al. 2012). It is important here to cite that a positive correlation between browning and antioxidant capacity of Maillard reaction products (MRPs) was identified in different model systems (Manzocco et al. 2000).

It is necessary to remind that the oxygen found in the drying atmosphere in RAD_{AIR} sample is consumed in the early periods of the closed- drying process and then no longer of oxygen for the rest of drying period is available. The $RAD_{NITROGEN}$ sample showed the lowest DPPH inhibition activity with a significant difference between $RAD_{NITROGEN}$ and other drying methods (except RAD_{AIR}). In the $RAD_{NITROGEN}$ assay, as the air surrounding the sample was replaced with an inert gas (N_2), the oxidation reactions were avoided and the antioxidant activity of the product was expected to be high (Fig. 3). However, the higher antioxidant activity of hot air and RAD_{AIR} samples compared to $RAD_{NITROGEN}$ may be explained by the formation of partially oxidized polyphenols that exhibit a stronger antioxidant activity than oxidized ones (Kamiloglu et al. 2016).

İncedayi et al. (2016) reported DPPH inhibition values of hot air dried apricots at 50 °C and 75 °C of 56.72 and 67.12%, respectively.

ABTS scavenging activity

The ABTS scavenging activity values of RAD-type dried samples: RAD_{MIX}, $RAD_{NITROGEN}$, and RAD_{AIR} exhibited 68.74, 64.49 and 61.61 µmol TE g^{-1} dm, respectively, that were close to that of the fresh sample (63.36 µmol TE g^{-1} dm) without significant difference between them ($p < 0.05$), with the highest value attributed to RAD_{MIX} sample (Fig. 4). The similarity in ABTS results between the three different types of RAD-type samples and fresh sample demonstrates the high effectiveness of the RAD system in preserving the antioxidant activity of the product. Güçlü et al. (2006) observed low values in fresh and dried Hacihaliloglu apricot variety with 3.50 and 16.16 µmol TE g^{-1} dm, respectively. The difference in results for the same apricot variety could be explained by the difference of the conditions of the procedure applied.

Total flavonoid content

The results presented in Fig. 5 showed a non-significant difference in the total flavonoid content (TFC) between fresh (or freeze-drying), vacuum, hot air and RAD_{MIX} samples (Fig. 5). The RAD_{MIX} sample shows an advantageous role of reducing gas (hydrogen) compared with both $RAD_{NITROGEN}$ and RAD_{AIR}. Ouchemoukh et al. (2012) found similar results in both methanolic and ethanolic extracts of dried apricots.

In the present study, a moderately high drying temperature (70 °C) was chosen for application in RAD system in order to verify its maximum possible effects on both color and bioactive compounds, in addition to simulating the industrial drying conditions. If a lower temperature was selected thus one would expect to have less change in product properties, which could be more close to fresh notes of fruit. Although the hot air and vacuum methods benefit from the formation of browning products with the antioxidant capacity property but characterized by its undesirable brown color, the RAD_{MIX} having the same temperature level showed an antioxidant capacity similar to that of the fresh sample.

On the other hand, the use of carbon dioxide known to possess a bactericidal property could play role in the microbial inactivation process, which needs to perform additional microbiological research to confirm this hypothesis.

This novel system of drying presented by its three types: RAD_{MIX}, $RAD_{NITROGEN}$ and RAD_{AIR}, demonstrates an interesting strategy to overcome the negative effects of an open cycle conventional drying methods. Hydrogen (H_2) has been approved by the food standard organizations as a food additive in the propellant category with the code E 949 for uses in the food industry such as the production of margarine. Different studies were performed for evaluating the safety conditions when hydrogen use is considered. The flammability of hydrogen in the air ranges from 4 to 75% (v/v), and the explosive limit is, in normal temperature and atmospheric conditions, between 18.3 and 59% (v/v)(Crowl and Jo 2007; Najjar 2013). However, a study showed that hydrogen diluted with nitrogen reduced the rate of normalized mass burning and the index of flammability, thereby, lowering the risk of explosion (Tang et al. 2009). The reducing property of hydrogen is characterized by its strong reducing capacity comparing to other reductants. This property allows us to benefit from this reducing property of hydrogen by using only low levels (as low as 0.1%, v/v) in the gaseous mixture of drying atmosphere, which constructs a safety key in its

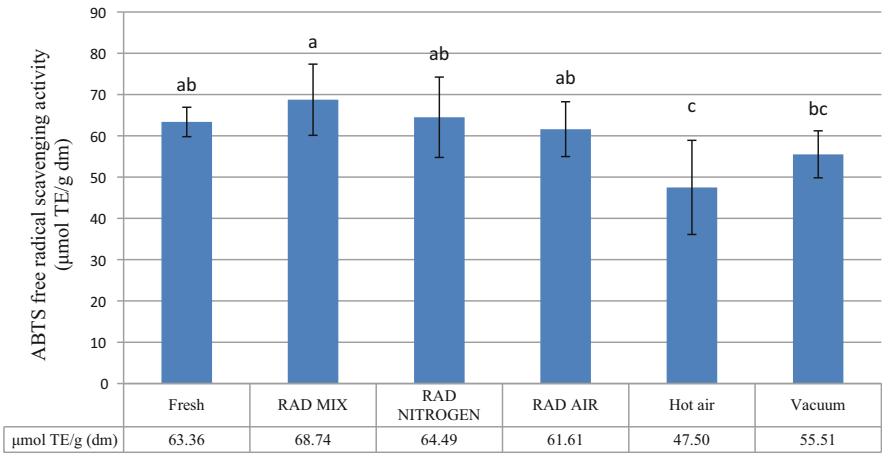


Fig. 4 ABTS scavenging activity of dried and fresh samples of Hacihaliloglu apricot variety

Different letters (a, b and c) indicate statistically significant difference ($p<0.05$). RAD_{MIX} :4% H_2, 5% CO_2, 91% N_2; $RAD_{NITROGEN}$: 100% N_2; RAD_{AIR}: air,; (n=3); dm: dry matter; TE: Trolox Equivalent.

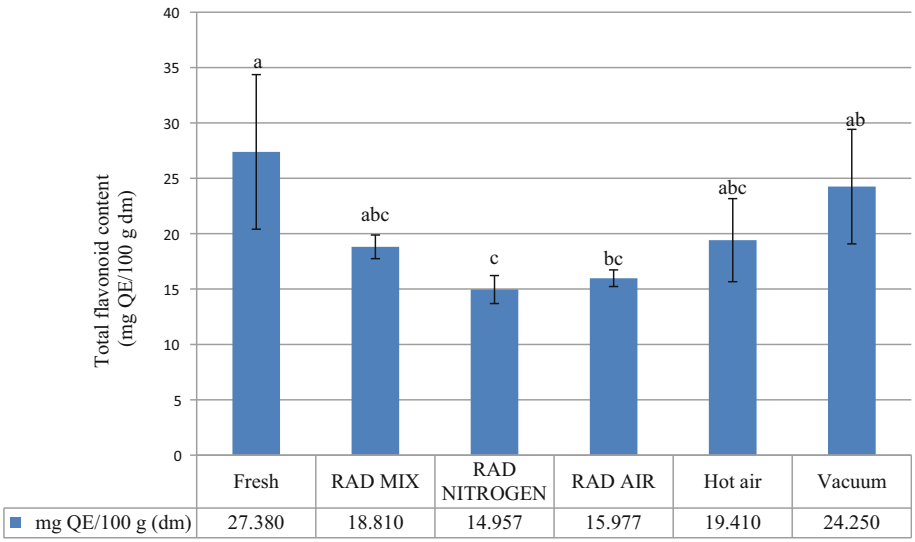


Fig. 5 Total flavonoid content of dried and fresh samples of Hacihaliloglu apricot variety

Different letters (a, b and c) indicate statistically significant difference ($p<0.05$). RAD_{MIX} :4% H_2, 5% CO_2, 91% N_2; $RAD_{NITROGEN}$: 100% N_2; RAD_{AIR}: Air, (n=3); QE: Quercetin Equivalents; dm: dry matter.

application in drying technology. It is important to remaind also the positive practice of dilution of hydrogen with the nitrogen for lowering the risk of explosion. Although the advantageous results of the present drying technique concerning the sensorial and the nutritional properties of foodstuffs it is important in the future to study the effect of this novel technology on other food characteristics such as the microbial and textural properties as well as an identification study of some specific bioactive compounds.

Conclusion

The results of this study show the advantageous role of the RAD technique in the preservation of the fresh color notes of the product. Concerning the nutritional property of the dried samples, this study demonstrates the protective effect of RAD technique especially the RAD_{MIX} type in preserving the bioactive compounds during the drying process. All the different methods used in this study to measure the antioxidant capacity of dried product (total phenolics, DPPH, ABTS and Flavonoids) showed the similarity between the RAD_{MIX} sample and the fresh one, which confirms the positive protective role of hydrogen included-reducing atmosphere drying technique for preserving the fresh nutritional notes of dried foodstuffs. These results must not surprise us when we know the reducing agent (hydrogen) used in the drying atmosphere plays different positive roles in preserving the nutritional and sensorial components of foodstuffs. The neutralization of many destructive substances present in the medium especially those of oxidative property such as the free radical, hydrogen peroxide and oxidant metallic ions could explain this positive protective effect of RAD_{MIX} technique. The oxygen- sensitive compounds characterizing the fresh notes of fruits and vegetables are the target of many destructive oxidation reactions occurred during processing and mediated by different oxidants such as oxygen, free radicals, some metallic ions and enzymes. These valuable compounds including polyphenols, carotenoids, unsaturated fatty acids and some vitamins such as C, E and β-carotene are protected industrially using different chemicals such as the sulfite compounds as in the case of apricot and grape drying. The amount of residuals of these chemicals is restricted by legislation due to its negative effects on consumer health. By the present technique, the food drying processors can solve this problem of residuals thanks to the property of the hydrogen as a volatile reducing agent with the non-residual property. On the other hand, the choice of an appropriate dryer is a very important task for food drying processors. Although the importance of the quality of the final dried product, the food processors don't prefer using sophisticated techniques such as freeze-drying due to its high costly equipment which, for example, reaches 4–8 times the hot air-drying costs (Ratti 2001), which in turn increases the price of the final dried product. Therefore, the selection of an appropriate dryer needs to be carefully evaluated (Chong and Law 2010). The freeze-drying technique is known for a long time for its property of preservation of the freshness notes and the nutritional compounds of the food product but unfortunately it is also defined by its high costly equipment in addition to an undesirable lightning effect on the sample color. The proved novel technique could be an appropriate alternative

to the freeze-drying process thanks to its simple and low costs of equipment, and preservation of fresh color and nutritional notes.

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References

Akin EB, Karabulut I, Topcu A (2008) Some compositional properties of main Malatya apricot (*Prunus armeniaca* L.) varieties. Food Chem 107(2):939–948. https://doi.org/10.1016/j.foodchem.2007.08.052

Albanese D, Cinquanta L, Cuccurullo G, Di Matteo M (2013) Effects of microwave and hot-air drying methods on colour, β-carotene and radical scavenging activity of apricots. Int J Food Sci Technol 48(6):1327–1333. https://doi.org/10.1111/ijfs.12095

Alwazeer D (2018) Kuru Gıdaların Rengini Muhafaza Etmeye Yönelik Yeni bir Teknik: İndirgen Atmosferik Kurutma. J Inst Sci Technol 8(4): 125–131. https://doi.org/10.21597/jist.418232

Chong CH, Law CL (2010) Drying of exotic fruits. In: Jangam SV, Law CL, Mujumdar AS (eds) Vegetables and fruits. Singapore, pp 1–42 (ISBN 978-981-08-7985-3)

Chong CH, Law CL, Figiel A, Wojdylo A, Oziemblowski M (2013) Colour, phenolic content and antioxidant capacity of some fruits dehydrated by a combination of different methods. Food Chem 141(4):3889–3896. https://doi.org/10.1016/j.foodchem.2013.06.042

Cossu A, Posadino AM, Giordo R, Emanueli C, Sanguinetti AM, Piscopo A, Poiana M, Capobianco G, Piga A, Pintus G (2012) Apricot melanoidins prevent oxidative endothelial cell death by counteracting mitochondrial oxidation and membrane depolarization. PLoS ONE 7(11):e48817. https://doi.org/10.1371/journal.pone.0048817

Crowl DA, Jo Y Do (2007) The hazards and risks of hydrogen. J Loss Prev Process Ind 20(2):158–164. https://doi.org/10.1016/j.jlp.2007.02.002

García-Alonso M, De Pascual-Teresa S, Santos-Buelga C, Rivas-Gonzalo JC (2004) Evaluation of the antioxidant properties of fruits. Food Chem 84(1):13–18. https://doi.org/10.1016/S0308-8146(03)00160-2

García-Martínez E, Igual M, Martín-Esparza ME, Martínez-Navarrete N (2013) Assessment of the bioactive compounds, color, and mechanical properties of apricots as affected by drying treatment. Food Bioprocess Technol 6(11):3247–3255. https://doi.org/10.1007/s11947-012-0988-1

Güçlü K, Altun M, Özyürek M, Karademir SE, Apak R (2006) Antioxidant capacity of fresh, sun- and sulphited-dried Malatya apricot (*Prunus armeniaca*) assayed by CUPRAC, ABTS/TEAC and folin methods. Int J Food Sci Technol 41(s1):76–85. https://doi.org/10.1111/j.1365-2621.2006.01347.x

Guiné RPF, Barroca MJ (2012) Effect of drying treatments on texture and color of vegetables (pumpkin and green pepper). Food Bioprod Process 90(1):58–63. https://doi.org/10.1016/j.fbp.2011.01.003

Hall CW (2007) Handbook of industrial drying. Dry Technol 6(3):571–573. https://doi.org/10.1080/07373938808916399

Hawlader MNA, Perera CO, Tian M (2006) Properties of modified atmosphere heat pump dried foods. J Food Eng 74(3):392–401. https://doi.org/10.1016/j.jfoodeng.2005.03.028

Ihns R, Diamante LM, Savage GP, Vanhanen L (2011) Effect of temperature on the drying characteristics, colour, antioxidant and beta-carotene contents of two apricot varieties. Int J Food Sci Technol 46(2):275–283. https://doi.org/10.1111/j.1365-2621.2010.02506.x

İncedayi B, Tamer CE, Sinir GÖ, Suna S, Çopur ÖU (2016) Impact of different drying parameters on color, β-carotene, antioxidant activity and minerals of apricot (*Prunus armeniaca* L.). Food Sci Technol 36(1):171–178. https://doi.org/10.1590/1678-457x.0086

Kamiloglu S, Pasli AA, Ozcelik B, Capanoglu E (2014) Evaluating the in vitro bioaccessibility of phenolics and antioxidant activity during consumption of dried fruits with nuts. LWT Food Sci Technol 56(2):284–289. https://doi.org/10.1016/j.lwt.2013.11.040

Kamiloglu S, Toydemir G, Boyacioglu D, Beekwilder J, Hall RD, Capanoglu E (2016) A Review on the effect of drying on antioxidant potential of fruits and vegetables. Crit Rev Food Sci Nutr 56:S110–S129. https://doi.org/10.1080/10408398.2015.1045969

Liu Y, Wu J, Miao S, Chong C, Sun Y (2014) Effect of a modified atmosphere on drying and quality characteristics of carrots. Food Bioprocess Technol 7(9):2549–2559. https://doi.org/10.1007/s11947-014-1295-9

López J, Uribe E, Vega-Gálvez A, Miranda M, Vergara J, Gonzalez E, Di Scala K (2010) Effect of air temperature on drying kinetics, vitamin c, antioxidant activity, total phenolic content, non-enzymatic browning and firmness of blueberries variety óneil. Food Bioprocess Technol 3(5):772–777. https://doi.org/10.1007/s11947-009-0306-8

Madrau MA, Piscopo A, Sanguinetti AM, Del Caro A, Poiana M, Romeo FV, Piga A (2009) Effect of drying temperature on polyphenolic content and antioxidant activity of apricots. Eur Food Res Technol 228(3):441–448. https://doi.org/10.1007/s00217-008-0951-6

Manzocco L, Calligaris S, Mastrocola D, Nicoli MC, Lerici CR (2000) Review of non-enzymatic browning and antioxidant capacity in processed foods. Trends Food Sci Technol 11(9–10):340–346

Megías-Pérez R, Gamboa-Santos J, Soria AC, Villamiel M, Montilla A (2014) Survey of quality indicators in commercial dehydrated fruits. Food Chem 150:41–48. https://doi.org/10.1016/j.foodchem.2013.10.141

Mujumdar AS, Law CL (2010) Drying technology: trends and applications in postharvest processing. Food Bioprocess Technol 3(6):843–852. https://doi.org/10.1007/s11947-010-0353-1

Najjar YSH (2013) Hydrogen safety: the road toward green technology. Int J Hydrog Energy. https://doi.org/10.1016/j.ijhydene.2013.05.126

O'Neill MB, Rahman MS, Perera CO, Smith B, Melton LD (1998) Color and Density of Apple Cubes Dried in Air and Modified Atmosphere. Int J Food Prop 1(3):197–205

Ouchemoukh S, Hachoud S, Boudraham H, Mokrani A, Louaileche H (2012) Antioxidant activities of some dried fruits consumed in Algeria. LWT Food Sci Technol 49(2):329–332. https://doi.org/10.1016/j.lwt.2012.07.022

Ozgen M, Reese RN, Tulio AZ, Scheerens JC, Miller AR (2006) Modified 2,2-Azino-bis-3-ethylbenzothiazoline-6-sulfonic Acid (ABTS) method to measure antioxidant capacity of selected small fruits and comparison to ferric reducing antioxidant power (FRAP) and 2,2'-Diphenyl-1-picrylhydrazyl (DPPH) methods. J Agric Food Chem 54(4):1151–1157. https://doi.org/10.1021/jf051960d

Ratti C (2001) Hot air and freeze-drying of high-value foods: a review. J Food Eng 49(4):311–319

Santos PHS, Silva MA (2009) Kinetics of L-ascorbic acid degradation in pineapple drying under ethanolic atmosphere. Dry Technol 27(9):947–954. https://doi.org/10.1080/07373930902901950

Sultana B, Anwar F, Ashraf M, Saari N (2012) Effect of drying techniques on the total phenolic contents and antioxidant activity of selected fruits. J Med Plants Res 6(1):161–167. https://doi.org/10.5897/jmpr11.916

Tang C, Huang Z, Jin C, He J, Wang J, Wang X, Miao H (2009) Explosion characteristics of hydrogen–nitrogen-air mixtures at elevated pressures and temperatures. Int J Hydrog Energy 34(1):554–561. https://doi.org/10.1016/j.ijhydene.2008.10.028

Vijaya Kumar Reddy C, Sreeramulu D, Raghunath M (2010) Antioxidant activity of fresh and dry fruits commonly consumed in India. Food Res Int 43(1):285–288. https://doi.org/10.1016/j.foodres.2009.10.006

Vital ACP, Croge C, Gomes-da-Costa SM, Matumoto-Pintro PT (2017) Effect of addition of Agaricus blazei mushroom residue to milk enriched with Omega-3 on the prevention of lipid oxidation and bioavailability of bioactive compounds after in vitro gastrointestinal digestion. Int J Food Sci Technol 52(6):1483–1490. https://doi.org/10.1111/ijfs.13413

Wojdyło A, Figiel A, Oszmiański J (2009) Effect of drying methods with the application of vacuum microwaves on the bioactive compounds, color, and antioxidant activity of strawberry fruits. J Agric Food Chem 57(4):1337–1343. https://doi.org/10.1021/jf802507j