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Research Article

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Effects of ultrasound pretreatment assisted drying methods on drying characteristics, physical and bioactive properties of windfall apples

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Abstract

BACKGROUND: Drying is one of the most important post-harvest processes in order to ensure that the products harvested in certain periods are consumed throughout the year. In this study, Golden Delicious, Oregon Spur and Granny Smith apple cultivars (fallen apples) were dried in open-sun, a controlled glasshouse, microwave oven (200 W), hybrid system (100 W + 60 °C), convective greenhouse (70 °C) and freeze-dryer (−55 °C) with and without ultrasound pretreatments.

RESULTS: Present findings revealed that the longest drying duration was observed in freeze-drying and the shortest in microwave drying. The greatest color change (ΔE) was observed in ultrasound pretreated Oregon Spur apples dried in a controlled glasshouse. The greatest total phenolics (40.08 mg GAE g^{-1}), DPPH (2,2-diphenyl-1-picrylhydrazyl) inhibition activity (46.96%), FRAP (ferric reducing ability of plasma) antioxidant activity (68.01 μg Trolox g^{-1}) and ascorbic acid content (1.52 mg AAE g^{-1}) were observed in open sun-dried Granny Smith apples without ultrasound pretreatment.

CONCLUSIONS: Generally, microwave and hybrid drying yielded better outcomes for bioactive, HMF (5-hydroxymethyl-2-furfural) and drying characteristics of windfall apples.
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Keywords: apple; ultrasound; texture; ascorbic acid; phenolic content; color

INTRODUCTION

Apple plays a great role in healthy nutrition and is among the most produced and consumed fruit species.[1] According to 2019 data, 87.236.221 tons of apple are produced worldwide from 4 717 384 ha production lands.[2] In terms of annual production quantities, China, the United States and Turkey are the leading producers.[3]

Apple is commonly consumed in Western diets.[4] Total phenolics (TPs) and ascorbic acid quantity of apples play an important role in sensory quality of fresh and processed fruits.[5] Apples are also known to have health-promoting antioxidant parameters and have a high antioxidant activity as compared to the other commonly consumed fruits and vegetables.[6]

Windfall and waste fruits mostly have high moisture contents and different physical characteristics such as shape, size, color, and damage levels. Furthermore, they may have greater nutritional attributes in some cases.[7] Long-term exposure to high heat levels may result in color loss and significant degradation of heat-sensitive substances. High heat levels may also reduce antioxidant capacity of the dried products.[8] Food loss and waste along the production lines result in different volumes of waste generated at each stage. According to the Food and Agriculture Organization of the United Nations (FAO), food waste is estimated as 413 t at the production stage, 293 t at the postharvest and storage stage,148 t during the processing.[9] Food types such as fruits, vegetables, poultry, nuts, cereals, etc. are wasted in different quantities at each stage. Approximately, 30% of fruits and vegetables are wasted at the retail and consumption stage, 26% of meat, poultry, and fish, 15% of nuts, and 41% of sugars and sweeteners.[10] Therefore, drying is among the most suitable method to regain these waste fruits. By means of proper drying, waste fruits could compete with regular ones in terms of both physical and biochemical characteristics.[11]

Drying is among the oldest methods used for processing and preservation of foodstuff. Various physical and chemical changes are encountered during the process of drying. Such changes designate sensory and nutritional attributes of the final products.[12] Long-term exposure to high heat levels may result in color loss and significant degradation of heat-sensitive substances. High heat levels may also reduce antioxidant capacity of the dried products.[13] Additionally, new substances are formed through Maillard reaction during the drying process. HMF (5-hydroxymethyl-2-furfural) is among these products. HMF is a heat-

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originated indicator in apple-like products. It is also used as an important color indicator to monitor heat treatment during food processing.[14]

Color is an important quality parameter for foodstuff. Color is also directly related to nutritional attributes of the dried products.[15] Drying processes may result in color changes and nutritional losses. Colored substances play a great role in boosting immune system and reduction of degenerative disease risks.[16]

Ultrasound moves molecules apart as they pass through a liquid, while expansion cycles take place when negative pressure is exerted on the liquid. Cavitation bubbles occur when the dilution cycle, which varies depending on the purity and type of ultrasound liquid with a sufficient level, exceeds the tensile strength.[17] Depending on the system properties, the bubbles continue to vibrate at the same frequency as the applied ultrasound. All these effects affect the external resistance and mechanical mixing should affect mass transfer in a similar way.[18] The microbubbles that occur after cavitation occur at pre-existing weak points in the liquid. When cavitation occurs, the growth of sound waves is due to the absorption of energy from micro gas bubbles irradiated with the help of ultrasound. The intensity of the sound affects the cavitation, and when a high intensity occurs, cavitation can grow rapidly.[19] Ultrasound pretreatments used both during the drying process and before to remove moisture from the product positively influence characteristics of final product. For instance, ultrasound applied during the drying process may improve quality of dried product because of non-thermal nature of the ultrasounds. Ultrasound could also reduce drying durations and drying process for heat-resistant substances could be conducted at lower temperatures.[20]

In drying process, moisture is removed from the products to prevent spoilages encountered in open-sun drying and to prolong shelf life. Several new methods have been developed and used in industrial drying operations. Although hot-air convective drying is the most common and easiest method, low product quality, high energy consumption, color and flavor losses significantly limit the use of this method. To overcome such deficiencies, microwave drying and combined (microwave-assisted convective) drying methods have been developed. These methods offer high quality final products, short drying durations and preserved color, taste and flavor. Despite various advantages, these methods may result in fruit browning and taste loss due to excessive heat exposure.[21-23] Among various drying methods, freze-drying offers the best final product quality. However, high operational costs and relatively longer drying durations are accepted as the most important disadvantages of freeze-drying. In the literature, there are studies in which combined or hybrid drying methods are preferred in apple drying.[6,11,13,24-28] Combination of microwave and convective drying was used in the majority of these studies. However, there are no studies in the literature considering the drying of windfall apples and ultrasound pretreatment drying processes.

The aim of this study is to dry windfall apple cultivars with and without ultrasound pretreatment by different drying methods and to perform a comparative analysis of the determined chromatic parameters, TP and antioxidant activities, ascorbic acid and HMF contents.

MATERIAL AND METHODS

Fresh fruit

Windfall apples of Golden Delicious, Oregon Spur and Granny Smith cultivars to be used in present experiments were collected from the orchards of Yeşilhisar town of Kayseri province in Turkey. These apples were collected from 2 m canopy diameter of the trees within 10 days following the harvest season. The apples were then cleaned and sorted into small packets and kept at +4 °C until analyses.

Drying process

Initially, windfall apples were collected, and decayed sections were removed. They were washed and seeds were removed with the use of apple de-seeder. Fresh products then were sliced in 1.4 mm cylindrical slices. To determine initial moisture content, 100 g samples were dried in an oven (Memmert UN55; Germany) at 70 °C for 24 h in three replicates and average moisture content was determined. Drying process was sustained until an equilibrium moisture. Drying methods included open-sun, controlled glasshouse, microwave oven (200 W), hybrid system (100 W + 60 °C), air-convective dryer (70 °C) and freeze-dryer (−55 °C). For sugar-containing products, a drying temperature of 60 to 80 °C is necessary to prevent non-enzymatic browning (Maillard reaction) and to preserve its quality.[29] Some preliminary tests were performed before the drying experiments started. In addition, some previous apple drying studies were investigated.[1,3,30,31]

Moisture contents (wet basis, w.b.) were determined with the use of Eqn (1).[32]

$$M_c = \frac{W_i - W_f}{W_i} \times 100 \quad (1)$$

where M_c represents moisture content (%, wb), W_i represents the initial weight of the product (in grams) and W_f represents the final weight of the product (in grams).

Open-sun and controlled glasshouse drying

Samples were dried in Kayseri province between the hours 08:00–18:00 at 25.8–42.5 °C (mean temperature: 25.8 °C) and 48.75% relative humidity under direct sunlight. Controlled glasshouse has the characteristics of: 72 m^2 (6 m × 12 m), polycarbonate cover (8 mm, 80–85% light transmittance), steel framework, single gable roof, four ventilation and one circulation fans for homogeneous air distribution. During the drying process, glasshouse mean temperature was measured as 35.02 °C and relative humidity as 34.20%. Glasshouse sidewalls are 4 m high and ridge height is 5 m. Climate parameters (temperature, relative humidity, wind speed and direction) could be arranged with the aid of a control panel equipped with sensors. Sample weights were measured every 2 h in open-sun drying and 1.5 h in controlled glasshouse by using a precise balance (±0.001 g) (Precisa, Sweden). Weighing was completed in 20 s and samples were replaced into drying environment.[33]

Air-convective drying

The air-convective drying experiments were performed in hybrid dryer (Arçelik KMF 833 I; Turkey). In hybrid dryer, microwave and air-convective characteristics could simultaneously be used. Ambient temperature could be arranged from 40 to 280 °C. Air-convective drying processes were run at 0.5 m s^{-1} air flow rate and 70 °C temperature. The oven has a fan for air circulation, perforated polyamide platforms and trays to hold the samples. An AUTOCAD drawing of hybrid dryer is presented in Fig. 1. In open-sun drying, apple samples were placed on 50 cm × 50 cm drying papers. Sample weights were measured every 1 h in 70 °C convective oven with the use of a precise balance.[25]

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Microwave drying

A programmable hybrid dryer (Arçelik KMF 833 I) was used. Microwaves are released from the upper sections of the oven. The oven is operated at 2.465 MHz frequency and 900 W output power. The device operated at 200 W power intensity for different drying runs. Microwave drying processes were run at 0.5 m s^{-1} air flow rate. The drying was performed according to present power and pre-determined time schedule. Sample weights were measured every 3 min in microwave oven with the use of a precise balance.[25]

Hybrid drying

Hybrid drying were carried out with the use of hybrid dryer (Arçelik KMF 833 I) with air-convective and microwave characteristics used to dry apple slices. In this hybrid oven, microwave and convective characteristics could simultaneously be used. Hybrid drying processes were run at 0.5 m s^{-1} air flow rate. The device operated at 100 W power intensity and 60 °C temperature for different drying runs. Sample weights were measured every 10 min in hybrid oven by a precise balance.[25]

Freeze drying

The laboratory-scale lyophilizator (Teknosem Toros TRS 2/2 V; Turkey) was used for freeze drying. The lyophilizator is operated at 10^{-3} mbar pressure and −55 °C condenser temperature. The condenser volume of the lyophilizer used in the study is 5.8 lt, and the vacuum pump capacity is 5.4 m^3. The device has 2.5 kg ice production capacity in 24 h. Products were weighed before freeze drying and then preserved in a freezer (VWR Symphony Model 414 005-087; USA) at ultra-low temperature (−80 °C) for 24 h.[34]

Ultrasound pretreatment

Ultrasound pretreatment was conducted in an ultrasonic bath (LAB.ULT.4045; Turkey) at 150 W heating power, 40 kHz frequency and room temperature (25 °C) for 20 min. Sliced apples were placed into a basket, supplemented with distilled water to have a 1:4 distilled water ratio in the ultrasound bath. Ultrasound-pretreated samples were kept on filter papers for 10 s to remove water on surfaces.[20]

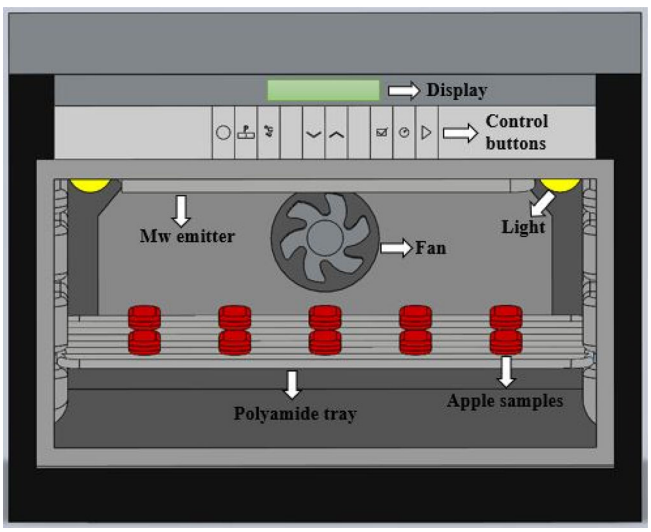


Figure 1. Schematic representation of microwave-convective hybrid dryer.

Color measurements

Color measurements of fresh and dry products were conducted with the use of a color measurement device (PCE-CSM 5 PCE Instruments; Germany). An average of 30 readings was taken for every drying treatment. Color measurements were taken from different points on the surface of dried apple slices. Before each test, device calibration was performed with the use of both black and white reflector plate. Measurements were performed in CIE-Lab color space: L^* (brightness, 0 dark, 100 bright), a^* (+ redness, − greenness) and b^* (+ yellowness, − blueness) values were measured. Measured CIE-L^*, a^* and b^* values were then used to calculate chroma (C) and total color change (ΔE) values.[21] The C and ΔE values were determined by the following equations[35]:

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

$$\Delta E = \sqrt{(L^* - L^*_0)^2 + (a^* - a^*_0)^2 + (b^* - b^*_0)^2} \quad (3)$$

where ΔE is the difference between the color of fresh and dried apple samples; L^*_0; a^*_0, and b^*_0 are the color parameters of fresh apples; L^*, a^*, and b^* are the color parameters of dried samples.

Energy consumption

Following equations were used to calculate energy consumptions of drying systems.[36] A digital watt-meter (Tt Technic PM-001, Turkey) was used to calculated energy consumption of freeze-dryer.

$$E_c = Av\rho_\alpha C_\alpha \Delta T t \quad (greenhouse\ and\ convective) \quad (4)$$

$$E_c = (P + Av\rho_\alpha C_\alpha \Delta T)t \quad (hybrid) \quad (5)$$

$$E_c = Pt \quad (microwave) \quad (6)$$

where E_c is total energy consumption of each drying system (in kW h), A is cross-sectional area of the plate on which the samples were placed (in m^2), v is air flow rate (in m s^{-1}), ρ_α is air density (in kg m^{-3}), C_α is air specific heat capacity (in kJ kg^{-1} °C), ΔT is temperature difference (in °C), t is total drying duration (in hours) and P is microwave power (in kilowatts).

In the present study, a thermal camera (Testo 872 thermal imager; Germany, 360 × 240 pixels and ± 0.05 °C) was used to measure the initial and final temperatures of the samples.

Hardness and fracturability texture profile

Textural properties are critical in determining the acceptance of dried products; therefore, hardness and fracturability tests of the dried apples were performed. Hardness and fracturability were settled as the indexes of texture. These parameters are associated with large voids in the material and expansion.[37] In textural measurements, dried samples were prepared with a radial orientation. The apple slices were placed on two parallel supports 20 mm apart, and each support was equipped with a 6-mm-diameter horizontal rod at the tip.[38]

Hardness and fracturability values of the dried samples were measured by a texture analyzer (TA.XT Plus; Stable Micro System Ltd, Godalming, UK) using a 100 kg load cell and a cylindrical probe (36 mm P/36). Measurement conditions were as follows: pre-test speed = 2.0 mm s^{-1}; test speed = 2.0 mm s^{-1}; post-test speed = 10 mm s^{-1}; distance = 2.5 mm. All measurements were replicated three times. In the tests, the hardness (in grams) was the maximum force required to break the dried sample, and the

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fracturability (in millimeters) was the distance at the point of break; a sample that breaks at a very short distance has a high fracturability.[39]

Biochemical analysis

Dry matter, ash and protein content (%)

Dry matter content was determined through drying samples at 105 °C until a constant mass in an oven (Memmert UN55; Germany). Approximately 1 g of dry sample was ashed in an oven (Protherm PLF 110; Turkey) at 550 °C for 8 h to determine ash content. Approximately 0.2 g of sample was used to determine nitrogen content with the use of Kjeldahl method. Resultant nitrogen values were then multiplied by a coefficient of 6.25 to get crude protein content.[40]

Extraction

Extraction was performed to measure TPs and antioxidant activity of dried apples. Before bioactivite analyses, dried apples were ground using a grinder (Bosch TSM6A014R). For this purpose, 3 g of dried apple powder was supplemented into 25 g ethanol (96%). Resultant mixture was processed in an ultrasonic bath (LAB.ULT.4045) for 15 min. Then, samples were centrifuged at 1000 rpm for 10 min (Sigma 4-16KS; Germany) and filtered through 4.5 µm syringe filter. Resultant liquids were stored and protected from the light. Phenolics and antioxidant properties were determined.[41]

Antioxidant capacity

Antioxidant capacity of apple extracts was determined with the use of the FRAP (ferric reducing ability of plasma) method.[42] FRAP reactive was prepared through supplementing 2.5 mL 10 mmol L^{-1} TPTZ (2,4,6-tri(2-pyridyl)-*S*-triazine; Merck, Darmstadt, Germany) and 2.5 mL acetate buffer (0.3 mol L^{-1} pH 3.6) into 40 mmol L^{-1} hydrochloric acid (HCl) and 2.5 mL 20 mmol L^{-1} iron(III) chloride hexahydrate ($FeCl_3.6H_2O$) solution. For AC, 30 µL extract and 30 µL distilled water was supplemented with 900 µL FRAP reactive and the resultant mixture was kept at 37 °C for 30 min. Absorbance values were red in a spectrophotometer (UV1800; Shimadzu, Kyoto, Japan) at 595 nm. A calibration curve was generated with the use ethanol solutions of previously known Trolox concentrations and results were expressed in millimole Trolox equivalent per gram of dry apple.[41]

Antiradical activity

For this purpose, 100 µL samples was mixed with 3000 µL DPPH (2,2-diphenyl-1-picrylhydrazyl; Merck) (0.1 mmol L^{-1} in methanol), mixture was vortexed, incubated in the dark for 30 min and absorbance values were red in an ultraviolet-visible (UV-vis) spectrophotometer (UV1800; Shimadzu) at 517 nm.[43] DPPH radical scavenging activity of apple samples was calculated with the use of the following equation:

$$\%Inhibition = \left(\frac{A_c - A_s}{A_c}\right) \times 100 \quad (7)$$

where A_c is absorbance of control and A_s is absorbance of the extract (sample).

Total phenolics (TPs)

TPs of apple samples were determined with the use of Folin–Ciocalteu (Merck) method.[44] For this purpose, 100 µL apple extract was supplemented into 200 µL Folin–Ciocalteu phenol reactive and 2 mL distilled water solution. Resultant mixture was kept at 25 °C for 3 min, then supplemented with 1 mL sodium carbonate (Na_2CO_3) solution (Na_2CO_3 and water, 20:80, g mL^{-1}). Next, the solution was kept at 20 ± 1 °C for an hour, absorbance readings were performed in a spectrophotometer (UV1800; Shimadzu) at 765 nm. Gallic acid standard curves prepared at different concentrations were used to determine TP of the samples and results were expressed in milligrams of gallic acid equivalent (GAE) per gram of dry apple.[41]

Total ascorbic acid (TAA) content

To determine total ascorbic acid (TAA) content, 0.5 mL apple extract was supplemented with 0.5 mL 7.5% trichloroacetic acid, the resultant mixture was kept at 4 °C for 5 min and filtered (4.5 um). Then, 2 mL of distilled water was supplemented with 0.2 mL filtrate and 0.2 mL Folin–Ciocalteu reactive (1:10). Final solution was kept at room temperature (20 ± 1 °C) in the dark for 10 min and absorbance readings were performed in a spectrophotometer (UV1800; Shimadzu) at 760 nm. A calibration curve generated with the use of known vitamin C concentrations was used to determine TAA content of the samples and the results were given as milligrams of ascorbic acid equivalent (AAE) per gram of dry apple.[41]

HMF (5-hydroxymethyl-2-furfural) analysis

HMF (Merck) content of dried apples was determined with the use of high-pressure liquid chromatography (HPLC; Shimadzu, Tokyo, Japan) and photodiode array (PDA) detection. Standard HMF solution was prepared in distilled water with the use of chromatography liquid phase at 95:5 ratio (water and acetonitrile) at HPLC purity and standard solution of HMF at different concentration within the range of 6.25 to 50 ppm. Dried apples were ground in a laboratory-type grinder and 1 g sample was precisely (±0.001 g) weighed into 100 mL volumetric flask and dissolved in distilled water. Resultant solution was filtered through 0.45 µm cellulose filter and taken into a vial. Then, 20 µL filtrate was injected into HPLC at 1 mL min^{-1} flow rate and readings were performed at 285 nm wavelength. Dilution factor and standard calibration curves were taken into consideration while calculating the results. HMF content (in mg kg^{-1}) was calculated in accordance with the following principle.[27]

$$C_{HMF} = (A_N/A_C) \times C_1 \times \text{dilution ratio} \quad (8)$$

where A_N represents the HMF peak area of experimental solution, A_C the HMF peak area of standard HMF solution, C_1 the concentration of standard HMF solution (in mg kg^{-1}) and dilution ratio is the sample weight (in milligrams)/experimental samples weight (in kilograms).

Experimental design and statistical analysis

In this study, experiments were conducted in randomized blocks split plots experimental design with three replications where a replicate consisted of ten randomly selected slices from three apple cultivars to examine the effects of certain independent variables on the dependant responses. Pretreaments (two treatments, control and ultrasound pretreatment) were placed into main plots and drying methods (six methods) were placed into sub-plots. Each cultivar was statistically evaluated separately. The independent variables studied in the full factorial experimental design were cultivar, drying method and pretreatment. The independent variables were chosen in accordance with the

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current literature and preliminary tests. The dependent variables investigated were dry matter, ash, protein content, color, texture, HMF and bioactive properties.

Relationships between drying parameters were determined with the use of variance analysis (ANOVA). Significant means were compared with the use of Tukey's multiple comparison test at 95% significance level. The assumptions of normality of error terms were tested using Kolmogorov–Smirnov and Shapiro–Wilk tests. In addition, skewness and kurtosis values were taken into account for normality. It recommends that a threshold value of ±1.96 for samples less than 50, ±2.58 threshold for samples from 51 to 100, and ± 3.29 for samples larger than 100 should be used.[45] Since there were 108 samples in the present study, the threshold value for skewness and kurtosis values was taken as ±3.29.

Homoscedasticity was checked by the Levene test. Together with a homoscedasticity verification, the variance was compared using Tukey's test (homoscedastic distributions). Assumptions of constant variance were checked by plotting residual *versus* fits scatter diagram.[46] The scatterplot graph of residuals *versus* actual values allowed noting that the residuals were distributed randomly around zero with no systematic pattern, satisfying the assumption of homoscedasticity and zero mean errors. Statistical analyses were conducted with the use of SPSS version 20.0 software.

RESULTS

Drying duration and energy consumption

Drying duration, final moisture content and energy consumptions are provided in Table 1. Freeze dryer had the longest drying duration, it was followed by open-sun drying and the shortest drying duration was observed in microwave drying system. Freeze dryer had 180 times longer drying duration than microwave drying. Ultrasound pretreatments reduced drying durations of all cultivars in hybrid system. Final moisture of apple samples varied between 7.41–22.80% (w.b.). Final moistures of ultrasound pretreated cultivars were lower. The greatest energy consumption was observed in freeze dryer due to longer drying durations, it was followed by convective drying and the lowest energy consumption was seen in open-sun drying. Greater energy consumptions are attributed to longer drying durations and lower energy consumptions are attributed to greater power outputs. Energy consumptions are directly proportional to drying durations. Present findings revealed that microwave drying had lower energy consumptions than the hybrid drying methods. Such a case was attributed to the combined energy consumption of both temperature and microwave power outputs.[25]

Dry matter, ash and protein content (%)

Dry matter, ash and protein contents of the cultivars under different drying systems, confidence interval with lower and upper bound, skewness and kurtosis values, the coefficients of determination (R^2, linear) obtained from residual values *versus* actual values are provided in Table 2. Dry matter content was found statistically significant ($P < 0.05$) for Golden Delicious, significant ($P < 0.01$) for Oregon Spur, and insignificant ($P > 0.05$) for Granny Smith. Ash values were determined as insignificant ($P > 0.05$) for all cultivars. While the change of the protein content was obtained statistically insignificant for Golden Delicious, and it was significant ($P < 0.01$) for Oregon Spur and Granny Smith cultivars. In addition, skewness and kurtosis values for dry matter, ash and protein contents were determined within the limits (±3.29) suitable for the number of samples (108 samples). The greatest coefficients of determination was obtained from dry matter content for Granny Smith, and obtained from ash content for Golden Delicious with values of 0.968 and 0.886, respectively. These values indicate that residuals are close to actual values.

Significant differences were not observed in control group of Golden Delicious cultivar. While ultrasound pretreated open sun-dried Golden Delicious apples had the lowest dry matter content (84.36%), the other treatments were all placed into the same statistical group. The greatest ash content (3.19%) was obtained from the control group of microwave-dried Golden Delicious apples and the lowest value (2.68%) was obtained from glasshouse-dried samples. In ultrasound pretreatment groups, the greatest value

Table 1. Drying time, final moisture content and energy consumption of drying methods

	Golden Delicious			Oregon Spur			Granny Smith		
Drying method	DT (min)	FMC (%)	EC (kWh)	DT (min)	FMC (%)	EC (kWh)	DT (min)	FMC (%)	EC (kWh)
Control									
Open-sun	1200	16.55	—	1200	17.30	—	960	16.95	—
Glasshouse	720	17.22	12.29	720	18.09	10.13	720	16.95	11.61
Microwave	27	14.90	5.40	24	16.43	4.80	24	16.84	4.80
Hybrid	120	13.68	1.45	130	18.06	2.41	120	13.38	1.73
Convective	480	14.22	15.21	480	14.90	14.07	480	12.25	13.50
Freeze	4320	16.19	30.12	4320	22.80	30.12	4320	14.86	30.12
Ultrasound pretreatment									
Open-sun	1200	13.17	—	1080	12.01	—	960	14.03	—
Glasshouse	720	11.37	14.95	720	11.79	13.20	720	14.03	14.08
Microwave	21	10.69	4.20	24	12.31	4.80	24	11.66	4.80
Hybrid	110	11.58	1.69	90	14.90	2.61	110	11.38	2.46
Convective	480	7.42	14.90	480	10.57	13.70	480	9.51	15.15
Freeze	4320	10.20	30.12	4320	10.33	30.12	4320	13.63	30.12

Note: DT, drying time; FMC, final moisture content; EC, energy consumption.

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Table 2. Dry matter, ash and protein content of dried windfall apples*

Drying method	Golden Delicious			Oregon Spur			Granny Smith		
	Dry matter (%)	Ash (%)	Protein (%)	Dry matter (%)	Ash (%)	Protein (%)	Dry matter (%)	Ash (%)	Protein (%)
Control									
Open-sun	91.31^{a}	2.68^{b}	1.89^{c}	88.89^{b}	2.89^{ab}	1.57^{e}	88.29^{a}	2.63^{c}	2.67^{c}
Glasshouse	93.14^{a}	1.68^{d}	2.10^{b}	93.53^{ab}	2.73^{ab}	1.61^{e}	87.91^{a}	2.38^{c}	2.14^{d}
Microwave	92.64^{a}	3.19^{a}	1.73^{d}	94.11^{ab}	3.72^{ab}	2.02^{c}	91.08^{a}	3.16^{ab}	3.44^{ab}
Hybrid	91.85^{a}	1.96^{cd}	1.53^{e}	92.35^{ab}	1.62^{b}	2.55^{a}	85.14^{a}	3.13^{ab}	3.32^{b}
Convective	93.17^{a}	3.02^{ab}	2.55^{a}	94.59^{a}	3.51^{a}	1.82^{d}	88.85^{a}	2.77^{bc}	3.65^{a}
Freeze	92.98^{a}	2.07^{c}	1.82^{cd}	94.42^{ab}	4.02^{a}	2.19^{b}	90.32^{a}	3.27^{a}	3.47^{ab}
Ulltrasound pretreatment									
Open-sun	84.36^{b}	2.13^{bc}	2.30^{d}	85.29^{b}	1.69^{b}	2.34^{c}	89.08^{a}	1.05^{c}	3.12^{b}
Glasshouse	91.98^{a}	2.80^{a}	1.77^{e}	91.65^{a}	1.67^{b}	1.98^{d}	89.72^{a}	1.60^{b}	2.38^{c}
Microwave	91.22^{a}	1.49^{d}	3.89^{a}	90.25^{a}	1.68^{b}	2.59^{b}	88.40^{a}	1.64^{b}	3.60^{a}
Hybrid	91.81^{a}	2.16^{b}	2.80^{c}	92.32^{a}	1.83^{ab}	2.99^{a}	86.11^{a}	1.96^{a}	3.03^{b}
Convective	89.35^{a}	1.86^{c}	3.83^{a}	90.99^{a}	1.62^{b}	3.10^{a}	86.24^{a}	1.65^{b}	2.52^{c}
Freeze	91.41^{a}	2.16^{b}	3.10^{b}	94.17^{a}	2.03^{a}	2.19^{c}	87.80^{a}	1.76^{ab}	2.92^{b}
Confidence interval (95%)	90.33–92.20	2.09–2.44	2.28–3.16	90.84–92.92	2.14–2.86	2.08–2.41	87.35–89.14	2.00–2.49	2.98–3.43
Skewness-kurtosis	−1.40–2.94	0.45–−0.83	1.53–1.77	−0.88–0.43	1.16–0.43	0.38–−0.75	−0.41–0.01	0.05–−1.29	0.59–0.77
F Values	3.071*	0.484	2.045	7.378**	2.252	4.988**	2.179	0.955	24.773**
R^2	0.689	0.886	0.563	0.517	0.418	0.497	0.968	0.114	0.712

Mean values with different superscripts in the same column are significantly different; ± SEE, standard error of estimate. *Significant at $P < 0.05$, **significant at $P < 0.01$. The coefficients of determination (R^2, linear) obtained from residual values *versus* actual values.

(2.13%) was obtained from glasshouse-dried samples and the lowest value (1.49%) was obtained from microwave-dried samples. The greatest protein content (2.55%) was obtained from convective-dried Golden Delicious apples and the lowest value (1.53%) was obtained from hybrid drying method. In ultrasound pretreatments, the greatest value (3.89%) was obtained from microwave drying and the lowest value (2.30%) was obtained from open-sun drying.

The mean dry matter content of all treatments in control group of Oregon Spur cultivar was calculated as 92.98% and the greatest value (94.59%) was obtained from convective drying. In ultrasound pretreatments, the lowest dry matter content (85.29%) was obtained from open-sun drying and the other drying systems were all placed into the same statistical group. In terms of ash contents of control groups, the greatest value (4.02%) was obtained from freeze drying and the lowest value (1.62%) was obtained from hybrid drying. In ultrasound pretreatments, ash contents of the samples varied between 1.36 and 3.87%. In Oregon Spur control group, the greatest protein content was obtained from hybrid drying and the lowest value from freeze drying. In ultrasound pretreatment group of Oregon Spur cultivar, the greatest protein contents were obtained from convective (3.10%) and hybrid drying (2.99%) and the lowest value (1.98%) was obtained from glasshouse drying.

In Granny Smith cultivar, drying methods in both the control and ultrasound pretreatment groups were all placed into the same statistical group. In control groups, the greatest ash content (3.27%) was obtained from freeze drying and the lowest value (2.38%) from open-sun drying. In ultrasound pretreatment groups, the greatest value (3.60%) was obtained from microwave drying and the lowest value (2.12%) from open-sun drying.

Chromatic parameters

The mean L^*, a^*, b^* and ΔE parameters and statistical analysis for Golden Delicious apples are provided in Table 3. The L^* values of control treatments were greater than pretreated samples. However, a^* and b^* values were greater in ultrasound pretreated samples than in the control samples. In all cultivars, the difference of L^* value was statistically significant ($P < 0.05$) except for Golden Delicious cultivar. The change in all other color parameters (a^*, b^* and ΔE) were statistically significant ($P < 0.01$). Additionally, skewness and kurtosis values for L^*, a^*, b^* and ΔE were found within the limit values. The highest R^2 values were obtained from a^* in Golden Delicious (0.877) and Oregon Spur (0.867), and also determined as 0.933 and 0.905 in b^* and ΔE for Oregon Spur, respectively.

In Golden Delicious cultivar, the greatest L^* values were respectively observed in control groups of open-sun, freeze dryer, glasshouse and hybrid drying methods. The greatest a^* value (16.82) was observed in convective drying of ultrasound pretreatment groups and the greatest b^* values were observed in convective (37.76) and hybrid (36.12) drying of the control group samples. The greatest color change (22.91) was observed in convective drying of the control group samples.

Averages for color parameters of Oregon Spur cultivar are provided in Table 4. The greatest brightness (L^*) value (74.10) was observed in freeze drying of the control groups, the greatest redness (a^*,+) value (18.44) was observed in convective drying of ultrasound pretreatment groups and the greatest yellowness (b^*,+) value (42.70) was observed in open-sun drying of ultrasound pretreatment groups. The greatest color change (28.18) was observed in convective drying of the control groups and

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Table 3. Chromatic parameters and bioactive properties of Golden Delicious apples under different drying methods

		Chromatic parameters				Bioactive properties				
Drying methods	Pretreatment	*L**	*a**	*b**	Δ*E*	TP	Antiradical activity (DPPH)	Antioxidant capacity (FRAP)	TAA	HMF
Open-sun	Control	75.28 ± 1.03^{a}	5.21 ± 0.24	25.30 ± 0.94^{ef}	13.92 ± 1.47^{bc}	18.69 ± 0.02^{b}	32.46 ± 0.65^{a}	37.74 ± 2.26^{c}	0.78 ± 0.02^{b}	18.91 ± 0.95^{cd}
	Ultrasound	64.03 ± 3.37^{bc}	7.97 ± 1.93^{bc}	26.95 ± 3.37^{def}	14.44 ± 2.24^{bc}	23.75 ± 0.15^{a}	15.64 ± 1.57^{d}	22.99 ± 0.82^{ef}	0.54 ± 0.01^{de}	3.16 ± 0.16^{d}
Glasshouse	Control	74.49 ± 0.98^{a}	7.34 ± 0.60^{bcd}	23.91 ± 0.77^{f}	12.93 ± 0.98^{c}	15.91 ± 0.58^{c}	27.52 ± 0.59^{b}	34.83 ± 1.16^{c}	0.86 ± 0.02^{a}	32.79 ± 1.64^{c}
	Ultrasound	58.70 ± 0.42^{cd}	9.64 ± 0.78^{b}	27.54 ± 0.08^{def}	14.19 ± 1.35^{bc}	3.95 ± 0.08^{e}	21.22 ± 0.28^{c}	18.12 ± 0.26^{g}	0.49 ± 0.01^{ef}	8.21 ± 0.41^{d}
Microwave	Control	71.18 ± 0.77^{ab}	7.22 ± 1.54^{bcd}	31.06 ± 1.25^{bcd}	15.89 ± 3.17^{abc}	5.78 ± 0.12^{d}	20.93 ± 2.02^{c}	14.24 ± 0.31^{h}	0.63 ± 0.01^{c}	420.38 ± 21.02^{a}
	Ultrasound	63.78 ± 6.52^{bc}	5.97 ± 1.06^{cd}	26.62 ± 2.58^{def}	13.10 ± 0.78^{c}	1.98 ± 0.34^{g}	8.58 ± 0.81^{ef}	23.20 ± 1.08^{ef}	0.34 ± 0.01^{hi}	135.94 ± 6.80^{b}
Hybrid	Control	74.32 ± 1.71^{a}	5.75 ± 0.81^{cd}	36.12 ± 1.20^{ab}	20.54 ± 3.40^{ab}	2.16 ± 0.11^{fg}	11.04 ± 0.29^{e}	12.85 ± 0.53^{h}	0.45 ± 0.06^{fg}	2.67 ± 0.13^{d}
	Ultrasound	52.61 ± 6.18^{d}	7.97 ± 0.92^{bc}	25.49 ± 1.21^{ef}	15.45 ± 3.16^{bc}	0.69 ± 0.02^{e}	3.67 ± 0.44^{g}	27.25 ± 0.65^{d}	0.30 ± 0.02^{i}	3.33 ± 0.17^{d}
Convective	Control	68.47 ± 3.02^{ab}	10.32 ± 0.74^{b}	37.76 ± 1.28^{a}	22.91 ± 2.88^{a}	3.63 ± 0.12^{e}	16.61 ± 0.60^{d}	48.94 ± 2.47^{a}	0.41 ± 0.01^{gh}	4.32 ± 0.22^{d}
	Ultrasound	68.03 ± 1.58^{abc}	16.82 ± 0.90^{a}	33.53 ± 0.70^{abc}	20.83 ± 1.13^{ab}	2.12 ± 0.79^{g}	5.64 ± 0.91^{fg}	44.27 ± 1.02^{b}	0.29 ± 0.00^{i}	5.17 ± 0.26^{d}
Freeze	Control	75.15 ± 0.91^{a}	4.54 ± 0.57^{c}	29.58 ± 2.24^{cde}	14.45 ± 3.43^{bc}	3.17 ± 0.14^{ef}	23.51 ± 1.88^{c}	25.62 ± 0.59^{de}	0.59 ± 0.05^{cd}	0.12 ± 0.01^{d}
	Ultrasound	72.51 ± 3.62^{ab}	5.32 ± 1.64^{cd}	27.67 ± 2.58^{def}	14.05 ± 2.27^{bc}	3.90 ± 0.56^{e}	17.39 ± 0.43^{d}	20.79 ± 0.17^{fg}	0.57 ± 0.02^{cd}	0.22 ± 0.01^{d}
Confidence interval (95%)		65.68–70.75	6.70–8.98	27.75–30.84	14.76–17.36	4.61–9.68	14.13–19.90	23.76–31.38	0.46–0.58	12.87–92.91
Skewness-kurtosis		−1.08-0.55	1.56–2.45	0.60 to −0.80	0.92–0.02	1.28–0.08	0.09 to −0.81	0.60 to −0.70	0.48 to −0.61	2.71–6.35
F Values		1.326	13.552**	7.186**	9.674**	35.400**	8.466**	14.806**	6.993**	17.795**
R^2		0.533	0.877	0.682	0.827	0.432	0.505	0.970	0.492	0.922

Mean values with different superscripts in the same column are significantly different; ±SEE, standard error of estimate. *Significant at $P < 0.05$, **significant at $P < 0.01$. The coefficients of determination (R^2, linear) obtained from residual values *versus* actual values.
Note: Δ*E*, total color difference; *a*, greenness/redness; Antiradical activity (DPPH), DPPH (2,2-diphenyl-1-picrylhydrazyl) inhibition activity (% inhibition); Antioxidant capacity (FRAP), FRAP (ferric reducing ability of plasma) antioxidant activity (μg Trolox g^{-1}); *b*, yellowness/blueness; HMF, 5-hidroksimetil-2-furfural (mg kg^{-1}); *L*, brightness/darkness; TAA, total ascorbic acid (mg AAE g^{-1}); TP, total phenolic (mg GAE g^{-1}).

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Table 4. Chromatic parameters and bioactive properties of Oregon Spur apples under different drying methods

		Chromatic parameters				Bioactive properties				
Drying methods	Pretreatment	L^*	a^*	b^*	ΔE	TP	Antiradical activity (DPPH)	Antioxidant capacity (FRAP)	TAA	HMF
Open-sun	Control	67.88 ± 0.83^{ab}	11.70 ± 0.80^{cd}	39.74 ± 1.80^{abc}	$21.16 \pm 2.77^{a-d}$	22.13 ± 0.37^{b}	33.60 ± 0.53^{c}	40.81 ± 1.68^{b}	0.82 ± 0.10^{b}	15.43 ± 0.77^{c}
	Ultrasound	56.07 ± 6.22^{cde}	15.32 ± 0.28^{abc}	42.70 ± 1.92^{a}	24.93 ± 2.49^{ab}	26.20 ± 0.25^{a}	27.91 ± 0.53^{d}	35.55 ± 0.87^{c}	0.66 ± 0.00^{cde}	7.75 ± 0.39^{c}
Glasshouse	Control	68.97 ± 0.79^{ab}	9.65 ± 0.25^{de}	34.59 ± 0.79^{de}	15.82 ± 1.25^{cde}	11.71 ± 0.16^{c}	34.96 ± 1.67^{c}	37.61 ± 1.25^{c}	0.66 ± 0.08^{cd}	3.86 ± 0.19^{c}
	Ultrasound	47.01 ± 4.32^{e}	14.72 ± 1.71^{abc}	37.79 ± 3.02^{bcd}	24.97 ± 3.25^{ab}	10.30 ± 0.12^{d}	27.22 ± 1.40^{d}	27.48 ± 0.78^{d}	0.61 ± 0.02^{de}	18.32 ± 0.92^{c}
Microwave	Control	55.12 ± 2.03^{de}	13.93 ± 1.26^{bc}	42.34 ± 0.48^{ab}	27.47 ± 2.82^{ab}	9.75 ± 0.17^{d}	38.22 ± 5.38^{bc}	36.42 ± 1.02^{c}	0.95 ± 0.01^{a}	574.01 ± 28.70^{a}
	Ultrasound	51.25 ± 5.99^{e}	12.35 ± 0.28^{cd}	$38.52 \pm 1.27^{a-d}$	$22.09 \pm 3.05^{a-d}$	6.89 ± 0.18^{f}	40.23 ± 0.49^{b}	21.07 ± 0.82^{e}	0.76 ± 0.01^{bc}	52.50 ± 2.63^{b}
Hybrid	Control	62.68 ± 6.22^{bcd}	13.57 ± 3.53^{bc}	40.45 ± 0.72^{abc}	22.69 ± 4.15^{abc}	10.15 ± 0.16^{d}	20.78 ± 0.54^{ef}	17.27 ± 0.76^{f}	0.81 ± 0.04^{b}	66.76 ± 3.34^{b}
	Ultrasound	56.75 ± 1.95^{cde}	15.39 ± 0.68^{abc}	40.02 ± 0.91^{abc}	20.64 ± 0.63^{bcd}	3.98 ± 0.16^{h}	18.68 ± 0.22^{fg}	9.18 ± 0.21^{g}	0.50 ± 0.03^{ef}	6.90 ± 0.35^{c}
Convective	Control	55.17 ± 2.41^{de}	16.78 ± 0.26^{ab}	42.35 ± 1.22^{ab}	28.18 ± 1.84^{a}	6.08 ± 0.12^{g}	26.67 ± 0.33^{d}	9.72 ± 0.33^{g}	0.57 ± 0.00^{de}	14.10 ± 0.71^{c}
	Ultrasound	54.05 ± 1.77^{de}	18.44 ± 0.61^{a}	40.66 ± 1.22^{abc}	23.27 ± 1.52^{ab}	3.14 ± 0.24^{i}	14.17 ± 0.68^{g}	11.29 ± 0.14^{g}	0.39 ± 0.01^{f}	2.11 ± 0.11^{c}
Freeze	Control	74.10 ± 2.95^{a}	5.53 ± 0.67^{f}	36.77 ± 0.77^{cde}	15.13 ± 1.74^{de}	8.15 ± 0.59^{e}	46.26 ± 0.32^{a}	49.72 ± 2.08^{a}	0.73 ± 0.00^{bc}	2.50 ± 0.13^{c}
	Ultrasound	66.30 ± 2.21^{abc}	8.50 ± 0.98^{ef}	32.97 ± 2.61^{e}	13.16 ± 2.23^{e}	4.30 ± 0.19^{h}	24.11 ± 1.49^{de}	25.11 ± 0.47^{d}	0.58 ± 0.00^{de}	3.86 ± 0.19^{c}
Confidence interval (95%)		56.73–62.50	11.73–14.25	37.97–40.18	19.91–23.35	7.89–12.57	26.24–32.56	22.35–31.18	0.62–0.72	10.74–117.17
Skewness-kurtosis		0.12 to −0.74	−0.51 to −0.54	−0.71-0.12	−0.26 to −0.82	1.33–0.79	0.22 to −0.75	0.12 to −1.15	0.10 to −0.42	3.07–8.10
F Values		4.703**	17.399**	10.440**	8.006**	68.739**	9.289**	16.546**	7.687**	6.515**
R^2		0.682	0.867	0.933	0.905	0.352	0.786	0.734	0.536	0.891

Mean values with different superscripts in the same column are significantly different; ±SEE, standard error of estimate. *Significant at $P < 0.05$, **significant at $P < 0.01$. The coefficients of determination (R^2, linear) obtained from residual values *versus* actual values.

Note: ΔE, total color difference; *a*, greenness/redness; Antiradical activity (DPPH), DPPH (2,2-diphenyl-1-picrylhydrazyl) inhibition activity (% inhibition); Antioxidant capacity (FRAP), FRAP (ferric reducing ability of plasma) antioxidant activity (μg Trolox g^{-1}); *b*, yellowness/blueness; HMF, 5-hidroksimetil-2-furfural (mg kg^{-1}); *L*, brightness/darkness; TAA, total ascorbic acid (mg AAE g^{-1}); TP, total phenolic (mg GAE g^{-1}).

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Table 5. Chromatic parameters and bioactive properties of Granny Smith apples under different drying methods

Drying methods	Pretreatment	Chromatic parameters				Bioactive properties				
		L^*	a^*	b^*	ΔE	TP	Antiradical activity (DPPH)	Antioxidant capacity (FRAP)	TAA	HMF
Open-sun	Control	60.76 ± 4.17^{bcd}	16.00 ± 0.77^{abc}	46.10 ± 1.77^{a}	38.37 ± 1.77^{ab}	40.08 ± 0.14^{a}	46.96 ± 1.16^{a}	68.01 ± 0.62^{a}	1.52 ± 0.03^{a}	52.50 ± 2.63^{c}
	Ultrasound	46.58 ± 0.82^{ef}	17.88 ± 1.08^{ab}	48.95 ± 0.71^{a}	42.55 ± 1.33^{a}	20.70 ± 0.25^{b}	18.32 ± 0.91^{e}	22.31 ± 0.58^{h}	0.52 ± 0.02^{f}	0.10 ± 0.01^{e}
Glasshouse	Control	55.43 ± 2.64^{de}	14.74 ± 0.76^{abc}	41.03 ± 1.83^{ab}	34.99 ± 3.11^{ab}	19.07 ± 0.44^{b}	31.10 ± 0.33^{cd}	38.96 ± 2.34^{cd}	1.08 ± 0.12^{b}	15.67 ± 0.78^{d}
	Ultrasound	42.45 ± 3.36^{f}	15.50 ± 1.18^{abc}	37.15 ± 0.65^{bc}	35.05 ± 1.36^{ab}	12.93 ± 0.18^{c}	21.43 ± 0.87^{e}	13.33 ± 2.94^{i}	0.69 ± 0.02^{de}	20.05 ± 1.00^{d}
Microwave	Control	69.39 ± 5.45^{ab}	6.99 ± 3.39^{ef}	29.78 ± 7.63^{cde}	19.78 ± 9.76^{cde}	9.33 ± 0.19^{d}	33.69 ± 1.16^{bcd}	13.68 ± 0.23^{i}	0.81 ± 0.00^{cd}	121.18 ± 6.06^{b}
	Ultrasound	64.44 ± 5.12^{abc}	11.49 ± 3.56^{cde}	34.61 ± 3.59^{bcd}	23.76 ± 3.99^{cd}	7.77 ± 0.13^{de}	34.81 ± 1.38^{bc}	30.18 ± 2.80^{fg}	0.82 ± 0.01^{c}	132.81 ± 6.64^{a}
Hybrid	Control	72.25 ± 2.99^{a}	8.90 ± 2.80^{def}	32.04 ± 3.65^{cde}	21.46 ± 3.92^{cde}	5.96 ± 0.08^{e}	28.36 ± 0.74^{d}	29.94 ± 0.61^{fg}	0.68 ± 0.03^{de}	3.02 ± 0.15^{e}
	Ultrasound	58.73 ± 3.02^{cd}	13.08 ± 0.85^{bcd}	33.55 ± 1.31^{bcd}	23.31 ± 2.69^{cde}	6.39 ± 0.10^{e}	39.70 ± 5.56^{b}	54.72 ± 3.02^{b}	0.76 ± 0.04^{cd}	1.63 ± 0.08^{e}
Convective	Control	70.38 ± 3.43^{ab}	11.27 ± 1.40^{cde}	33.41 ± 1.10^{bcd}	23.27 ± 1.02^{cde}	5.94 ± 0.14^{e}	22.27 ± 0.55^{e}	43.22 ± 2.75^{c}	0.62 ± 0.03^{ef}	16.67 ± 0.83^{d}
	Ultrasound	66.06 ± 2.74^{abc}	18.83 ± 1.58^{a}	36.86 ± 1.30^{bc}	28.35 ± 1.99^{bc}	3.64 ± 0.26^{e}	18.84 ± 2.51^{e}	25.66 ± 1.64^{gh}	0.49 ± 0.01^{f}	2.03 ± 0.10^{e}
Freeze	Control	72.41 ± 2.05^{a}	4.55 ± 1.89^{f}	26.50 ± 2.69^{de}	15.40 ± 2.50^{de}	6.79 ± 2.36^{e}	28.54 ± 2.53^{d}	31.48 ± 0.40^{ef}	0.68 ± 0.06^{de}	15.93 ± 0.80^{d}
	Ultrasound	68.64 ± 0.95^{ab}	6.64 ± 0.67^{ef}	23.98 ± 1.08^{e}	12.62 ± 1.25^{e}	5.80 ± 0.18^{e}	29.45 ± 0.43^{cd}	35.88 ± 0.60^{de}	0.72 ± 0.00^{cde}	1.17 ± 0.06^{e}
Confidence interval (95%)		58.90–65.68	10.53–13.78	32.78–37.89	23.33–29.82	8.62–15.44	26.57–32.34	28.69–39.20	0.69–0.88	16.49–47.24
Skewness-kurtosis		−0.77 to −0.42	−0.28 to −1.02	0.19 to −0.59	0.11 to −1.08	1.89–3.04	0.56 to −0.16	0.73–0.14	1.73–2.71	1.55–0.29
F Values		11.766**	13.651**	32.591**	38.641**	27.010**	3.068*	2.400	2.564*	77.655**
R^2		0.310	0.538	0.349	0.311	0.346	0.878	0.943	0.575	0.917

Mean values with different superscripts in the same column are significantly different; ±SEE, standard error of estimate. *Significant at $P < 0.05$, **significant at $P < 0.01$. The coefficients of determination (R^2, linear) obtained from residual values *versus* actual values.
Note: ΔE, total color difference; *a*, greenness/redness; Antiradical activity (DPPH), DPPH (2,2-diphenyl-1-picrylhydrazyl) inhibition activity (% inhibition); Antioxidant capacity (FRAP), FRAP (ferric reducing ability of plasma) antioxidant activity (μg Trolox g^{-1}); *b*, yellowness/blueness; HMF, 5-hidroksimetil-2-furfural (mg kg^{-1}); *L*, brightness/darkness; TAA, total ascorbic acid (mg AAE g^{-1}); TP, total phenolic (mg GAE g^{-1}).

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the lowest color change (13.16) was observed in freeze drying of ultrasound pretreatment groups.

Averages for color parameters of Granny Smith cultivar are provided in Table 5. In Granny Smith cultivar, the greatest L^* values were observed in freeze drying (72.41) and hybrid (72.25) drying of the control group samples. The lowest L^* value (42.45) was observed in glasshouse drying of ultrasound pretreatment groups. While the greatest a^* value (18.83) was observed in convective drying of the control groups, open-sun-dried samples had the greatest b^* values (48.95 and 46.10). The greatest color change (42.55) was observed in open-sun drying of ultrasound pretreatment groups.

Hardness and fracturability properties

Hardness and fracturability values and statistical groups for varieties, confidence interval with lower and upper bound, skewness and kurtosis values, the coefficients of determination (R^2, linear) obtained from residual values *versus* actual values are given in Table 6. Hardness values changed as statistically significant ($P < 0.01$) for Golden Delicious, insignificant ($P > 0.05$) for Oregon Spur, and significant ($P < 0.05$) for Granny Smith based on drying methods, while fracturability values were found as significant ($P < 0.01$) for Golden Delicious and Granny Smith, insignificant ($P > 0.05$) for Oregon Spur. Also, skewness and kurtosis values for fracturability were determined within the limits. However, these values were obtained for hardness values without the limit for Granny Smith (2.15–4.53). Fracturability tests had high R^2 values with the values of 0.995, 0.953 and 0.926 for Golden Delicious, Granny Smith and Oregon Spur, respectively.

In the Golden Delicious control groups, the highest hardness values were found in the glasshouse dried (510.19 gf – gram force) and the lowest ones was found in the lyophilizer dried (101.67 gf). In the ultrasound assisted group, the greatest values were found in the hybrid drying system as 438.98 gf, while open-sun drying, glasshouse, microwave and lyophilizer drying took place in the same statistical group with the lowest values. The highest hardness values of Oregon Spur cultivar was found in microwave drying with 294.00 gf, and the lowest means was found in hybrid drying with 98.30 gf. In the ultrasound assisted group, glasshouse and hybrid drying systems had the greatest hardness values with 475.71 and 442.98 gf, respectively. No difference was observed in the statistical groupings of the other drying methods ($P < 0.05$). The mean of all drying methods was 390.48 gf in the control group of Granny Smith cultivar, and this value was the highest mean between cultivar and ultrasound pretreated. Among the drying methods, the highest value of 885.38 gf was determined in the glasshouse drying. The lowest value was found in the products dried with lyophilizer. Hybrid and convective drying systems, which had very close values of 360.92 and 360.44 gf in the ultrasound assisted group, respectively. The lowest average was determined in the open-sun drying method.

Fracturability averages were evaluated according to the varieties and pretreatment, the highest average fracturability values of 1.92 mm^{-1} were obtained in the Oregon Spur ultrasound assisted, and the lowest average was 1.29 fracturability mm^{-1} in the Granny Smith control group. The highest fracturability values were obtained in the air-convective dried (3.78 fragility mm^{-1}) in the Golden Delicious control group, and in the glasshouse drying ultrasound group (3.65 fragility mm^{-1}). In Granny Smith cultivar, the highest values were determined in microwave drying with a fracturability of 3.45 and 2.88 mm^{-1} in both control and ultrasound pretreated groups. No significant difference was found in terms of statistical groupings in Oregon Spur untreated and ultrasound pretreated groups ($P < 0.05$).

Table 6. Average values of hardness and fracturability texture profile

	Golden delicious		Oregon Spur		Granny Smith	
Drying method	Hardness (gf)	Fracturability (mm^{-1})	Hardness (gf)	Fracturability (mm^{-1})	Hardness (gf)	Fracturability (mm^{-1})
Control						
Open-sun	391.20^{b}	0.85^{b}	144.33^{bc}	0.64^{a}	885.38^{a}	0.86^{b}
Glasshouse	510.19^{a}	2.40^{ab}	226.97^{abc}	1.04^{a}	256.83^{bc}	1.05^{b}
Microwave	168.96^{cd}	1.28^{b}	294.90^{a}	2.65^{a}	294.85^{bc}	3.45^{a}
Hybrid	204.47^{c}	0.82^{b}	98.30^{c}	1.67^{a}	421.91^{b}	0.67^{b}
Convective	453.66^{ab}	3.78^{a}	279.59^{ab}	1.84^{a}	285.34^{bc}	1.07^{b}
Freeze	101.67^{d}	0.46^{b}	142.25^{bc}	0.71^{a}	198.59^{c}	0.63^{b}
Ultrasound pretreatment						
Open-sun	241.64^{b}	0.93^{b}	252.15^{b}	2.39^{a}	176.12^{b}	0.58^{b}
Glasshouse	214.94^{b}	3.65^{a}	475.71^{a}	2.54^{a}	248.92^{ab}	1.43^{ab}
Microwave	184.36^{b}	1.02^{b}	228.34^{b}	1.14^{a}	234.06^{ab}	2.88^{a}
Hybrid	438.98^{a}	0.71^{b}	442.98^{a}	2.89^{a}	360.92^{a}	1.55^{ab}
Convective	272.85^{ab}	1.71^{b}	275.40^{b}	2.01^{a}	360.44^{a}	1.72^{ab}
Freeze	111.58^{b}	1.16^{b}	198.66^{b}	0.56^{a}	188.84^{ab}	1.96^{ab}
Confidence interval (95%)	226.61–322.48	1.15–1.98	214.59–295.34	1.29–2.06	259.89–392.14	1.15–1.82
Skewness-kurtosis	0.39 to −1.29	1.38–0.92	0.83–0.16	0.99–0.14	2.15–4.53	0.92–0.32
F Values	5.766**	9.152**	1.959	1.620	2.915*	11.194**
R^2	0.853	0.995	0.742	0.926	0.772	0.953

Mean values with different superscripts in the same column are significantly different; ±SEE, standard error of estimate. *Significant at $P < 0.05$, **significant at $P < 0.01$. The coefficients of determination (R^2, linear) obtained from residual values *versus* actual values.

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Bioactive properties

TPs, DPPH, FRAP, TAA and HMF values of Golden Delicious, Oregon Spur and Granny Smith cultivars and statistical analysis are provided in Tables 3–5, respectively. For Golden Delicious and Oregon Spur cultivars, the change of all bioactive properties were found to be statistically significant ($P < 0.01$). However, for Granny Smith cultivar, the difference of FRAP values were found to be statistically insignificant ($P > 0.05$), DPPH and TAA values were significant ($P < 0.05$), and TP and HMF values were found to be significant ($P < 0.01$). All skewness and kurtosis values for Golden Delicious were within the expected limits, while for Oregon Spur and Granny Smith only the HMF values were above the expected limits. HMF had the coefficients of determination with the values of 0.922, 0.917 and 0.891 for Golden Delicious, Granny Smith and Oregon Spur, respectively. In addition, FRAP had the greatest R^2 values as 0.970 and 0.943 for Golden Delicious and Granny Smith, respectively.

The greatest TPs were observed in sun-dried samples and the lowest in hybrid drying of ultrasound pretreatment groups (0.69 mg GAE g^{-1}). Free radical DPPH antioxidant is among the most commonly used compounds to determine radical scavenging activities.[47] In Golden Delicious apples, the greatest DPPH% inhibition value was observed in open-sun drying of the control group samples, followed by glasshouse drying of the control groups. The lowest value was observed in hybrid drying of the ultrasound pretreatment groups. For FRAP activity of Golden Delicious apples, the greatest value (48.94 μg Trolox g^{-1}) was observed in convective drying of the control group samples and the lowest value (12.85 μg Trolox g^{-1}) was observed in hybrid drying of the control groups. The greatest ascorbic acid content (0.86 mg AAE g^{-1}) was observed in glasshouse drying of the control group samples and the lowest values were observed in convective (0.29 mg AAE g^{-1}) and hybrid (0.30 mg AAE g^{-1}) drying of the control group samples. The greatest HMF content (420.38 mg kg^{-1}) was observed in microwave drying of the control group samples.

TPs, DPPH, FRAP, TAA and HMF values of Oregon Spur apples are provided in Table 4. In Oregon Spur cultivar, the greatest TPs (26.20 mg GAE g^{-1}) were observed in open-sun drying of the control group samples and the lowest value (3.14 mg GAE g^{-1}) in convective drying of ultrasound pretreatment groups. The greatest DPPH% inhibition (46.26%) was observed in freeze drying of the control group samples and the lowest (14.17%) in convective drying of ultrasound pretreatment groups. The greatest FRAP activity (49.72 μg Trolox g^{-1}) was observed in freeze drying of the control group samples and the lowest values were observed in convective drying (9.18 μg Trolox g^{-1}) of the control groups and hybrid drying (9.72 μg Trolox g^{-1}) of ultrasound pretreatment groups. The greatest ascorbic acid content (0.95 mg AAE g^{-1}) was observed in microwave drying of the control group samples and the lowest (0.50 mg AAE g^{-1}) in hybrid drying of ultrasound pretreatment groups. The greatest HMF content (574.01 mg kg^{-1}) was observed in microwave drying of the control group samples.

TPs, DPPH, FRAP, TAA and HMF values of Granny Smith apples are provided in Table 5. The greatest TPs (40.08 mg GAE g^{-1}) were observed in open-sun drying of the control group samples. The greatest DPPH antioxidant activity (46.96%) and the greatest FRAP (68.01 μg Trolox g^{-1}) were also observed in open-sun drying of the control group samples. The lowest FRAP values were observed in glasshouse drying of ultrasound pretreatment groups (13.33 μg Trolox g^{-1}) and hybrid drying of the control group samples (13.68 μg Trolox g^{-1}). The greatest ascorbic acid content (1.52 mg AAE g^{-1}) was observed in open-sun drying of the control group samples. The greatest HMF contents were observed in microwave drying of ultrasound pretreatment groups (132.81 mg kg^{-1}) and microwave drying of the control group samples (121.18 mg kg^{-1}).

DISCUSSION

Significant differences were observed in biochemical traits of the cultivars based on pretreatment and drying methods. Biochemical characteristics of the products largely depend on plant genetics, agronomic properties, soil properties and harvest times.[48] Significant losses are encountered in ascorbic acid contents during the drying processes and such losses are not reversed through oxidative processes during the rehydration.[49] Ascorbic acid is an essential nutrient. It serves as a biological antioxidant and offers protection against diseases.[50] High drying temperatures and long drying durations may degrade phenolic compounds and reduce antioxidant activity.[51] Similar effects were reported during the drying processes of Aronia fruits.[52] However, Igual *et al.*[53] reported that dry apricots had greater antioxidant activity than the fresh ones. Such a case may be related to greater antioxidant capacity of partially oxidized polyphenols than non-oxidized polyphenols[54] and formation of new compounds like Maillard reaction products.

Drying can degrade bioactive components in fruits due to high temperatures and long drying times.[55] Ultrasound pretreatment is one of the best way to preserve nutrients during drying. It has been determined that pretreatment preserves the natural flavor, color and heat-sensitive nutritive components of the fruits and reduces the drying time. Additionally, because of ultrasounds use of liquid media, the transport of solutes or liquids promotes nutrient loss, especially soluble nutrients.[12] Opalić *et al.*[12] indicated that prolonged ultrasound pretreatment resulted in a reduction in total phenols and flavonoids, as well as the antioxidant capacity of dried apples. In addition, the authors reported that sugar content and bioactive compounds decreased in apple samples subjected to long ultrasound pretreatment. TP content was greater in dried apple than in fresh samples. However, longest ultrasound pretreatment had lower TP as 3.38 mg g^{-1}, while the shortest pretreated samples had the highest TP with the value of 5.47 mg g^{-1}.[12]

In another study, it has been reported that an increase in A, B and E vitamin content can be observed after drying, but this effect tends to have a dual effect at the highest temperatures tested with ultrasound pretreatment.[56] Rodríguez *et al.*[14] reported that ultrasound-assisted drying of apple cubes also contributed to the reduction of quality loss of apple cubes regarding polyphenol content, flavonoid content, and antioxidant activity.

In general, microwave-dried products had greater antioxidant (DPPH) activity than the convective-dried products. Such a case was attributed to shorter drying durations and free radical scavenging activity of Maillard reaction products.[53] Additionally, increasing drying temperatures and microwave powers might have reduced TPs and antioxidant activity. Longer drying durations may result in oxidation and degradation of phytochemicals with a high antioxidant potential[54] and loss of bioactive properties.[36] Enzymatic and non-enzymatic browning reactions encountered during the drying process may also influence antioxidant characteristics.[52]

In the present study, this effect was observed in two of three apple cultivars, but not observed in Granny Smith cultivar. This phenomenon can occur in two directions, depending on the

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species and cultivars. In some apple cultivars, freeze drying increased porosity, then increased antioxidant (DPPH) activity. Thus, high phenolic levels of freeze drying could be related to such increasing efficiencies.[57] Similar findings were also indicated by Atalay and Erge[58] for the mushroom dried with the use of hybrid drying. The researchers reported that the antioxidant activity of the samples significantly increased with the increment of microwave power from 90 to 600 W. Authors also attributed this increase to the release of TPs from the tissues by the deterioration of the cell wall structure due to the intense heat by produced microwave. The higher polyphenol content in some of the dried apples than in fresh apples may be due to the presence of other antioxidant substances produced during drying and reacting with the Folin–Ciocalteu reagent.[59] In addition, ultrasound pretreatment of apples shortens the drying time with dehumidified air, reducing product exposure to hot air and oxygen. In this case, it probably contributed to the greater retention of the polyphenols. In addition, tissue damage caused by ultrasound and high temperature can lead to increased extractivity of polyphenols.[60]

In the present study, the lowest HMF contents were observed in freeze drying and the greatest in microwave drying. As compared to the other drying methods, microwave might have induced HMF formation. In general, ultrasound pretreated samples and longer drying durations yielded lower HMF values. Therefore, it could be stated that ultrasound pretreatments reduced HMF contents. Dried products generally have greater protein ratios due to water loss encountered during the process of drying. Similar with the present findings, Polat *et al.*[26] reported the greatest protein content (2.5%) of apples in hybrid drying (microwave + vacuum) for 30 min at 300 W to 400 mmHg drying conditions. Researchers also reported L^* values of different drying methods as between 53.23 and 78.27. It has been reported that exposure to ultrasonic waves tends to decrease L^* values. Since the ultrasound destruction of the cells releases enzymes responsible for the browning of the surface, which leads to the dark color. However, there is no no clear trend for either a^* or b^* values for all dried apple samples.[61]

Complying with the present findings, Vega-Gálvez *et al.*[6] reported DPPH values of dried Granny Smith apples at 0.5 m s^{-1} air flow rate and 40, 60 and 80 °C drying temperatures respectively as 1787.99, 3113.47 and 2142.96 µg mg^{-1}, TPs respectively as 31.94, 27.39 and 27.34 mg GAE 100 g^{-1}, ΔE color change values as 35.70, 28.15 and 18.75. Masztalerz *et al.*[28] dried apples with the use of osmotic dehydration pretreatments and different drying methods and reported FRAP values as between 1.96 and 14.23 mmol trolox 100 g^{-1} dm. Opalić *et al.*[12] applied different ultrasound pretreatment durations and reported the lowest TPs (3.38 mg g^{-1} s) for 54 min ultrasound pretreatment and 540 min convective drying (71.5 °C) and the greatest (5.47 mg g^{-1}) for 22.5 min ultrasound pretreatment and 720 min convective (71.5 °C) drying. The lowest FRAP value (2.5 mmol L^{-1} Fe(II) g^{-1}) was reported for 54 min ultrasound pretreatment and 540 min convective (71.5 °C) drying and the greatest (4.0 mmol L^{-1} Fe(II) g^{-1}) for 22.5 min ultrasound pretreatment and 720 min convective (71.5 °C) drying. Horuz[25] dried Golden Delicious apples with convective drying at 50, 60 and 70 °C temperatures and reported antioxidant capacity (DPPH, % inhibition) respectively as 28.29, 25.53 and 25.40%. Antioxidant activity (DPPH, % inhibition) was reported as 25.62% for hybrid drying (120 W + 60 °C). Al Juhaimi *et al.*[24] reported antioxidant activity of Granny Smith and Golden Delicious apples respectively as 52.49 and 34.04% for 70 °C oven drying and as 61.88 and 38.52% for 180 W microwave drying power. Rodríguez *et al.*[14] reported antioxidant (FRAP) activity of Granny Smith apples without ultrasound pretreatment, with ultrasound-1 (18.5 kW m^{-3}) and ultrasound-2 (30.8 kw m^{-3}) treatments respectively 51.2, 49.3 and 37.8 mg g^{-1} for 30 °C drying temperature, as 45.6, 40.4 and 39.6 mg g^{-1} for 50 °C drying temperature and as 38.1, 39.7 and 41.6 mg g^{-1} for 70 °C drying temperature. Similar with the present findings, Kaya[27] reported HMF content of Starking Delicious apples as 18.52 mg kg^{-1} for 65 °C drying temperature, 6.27 mg kg^{-1} for 15 min ultrasound pretreatment and as 5.41 mg kg^{-1} for 30 min ultrasound pretreatment. HMF value was reported as 312.69 mg kg^{-1} for 180 W microwave power, as 279.05 mg kg^{-1} for 15 min ultrasound pretreatment and as 189.53 mg kg^{-1} for 30 min ultrasound pretreatment.

The textural properties of dried samples depend on the behavior of the soluble solid phase and cellular matrix in the tissue, by different interactions with water. In air-convective drying, the surface moisture is quickly removed, hardness is described by the curing phenomenon, thus forming a harder outer layer on the fruit. Additionally, the amount and composition of pectin can affect the structure and textural properties of air-dried apple tissues.[62] Similar to the present study, Mothibe *et al.*[62] evaluated the hardness values for dried apples for different drying conditions. The hardness values were found to be 1533.102 gf for fluid bed dryer (70 °C). In addition, it was determined as 555.485 gf for 5 min pretreatment, 592.926 gf for 10 min pretreatment, 508.078 gf for 15 min pretreatment for the products dried in fluid bed dryer with ultrasound pretreatment applied. Khampakool *et al.*[63] determined the hardness values for dried bananas as 7.9 N and fracturability values as 1.6 mm^{-1} for freeze-drying. In three different microwave applications of Duan *et al.*[64] dried sweet potato, the hardness and fracturability values were approximately 4 N and 1.7 mm^{-1} for 0.125 W g^{-1} application, 7.2 N and 1.5 mm^{-1} for 0.225 W g^{-1} application and 8.0 N and 1.75 mm^{-1} for 0.370 W g^{-1} application, respectively.

CONCLUSION

In the present study, windfall apples of Golden Delicious, Oregon Spur and Granny Smith cultivars were dried without and with 20 min ultrasound pretreatment in open-sun (0.5 m s^{-1} air flow rate), controlled glasshouse, microwave (200 W), hybrid (100 W + 60 °C), convective (70 °C) and freeze dryer. Initial moisture content of Golden Delicious, Oregon Spur and Granny Smith apples was respectively measured as 85.22, 83.45 and 80.02% and final moisture contents varied between 7.42–22.80% (w.b.). Present findings revealed that ultrasound pretreatments reduced drying durations. For color parameters, control samples of all cultivars had greater L^* values, but ultrasound pretreated samples had greater a^* values. The greatest color change was observed in convective drying of Golden Delicious and Oregon Spur cultivars and open-sun drying of Granny Smith cultivar. The greatest energy consumption was observed in freeze dryer and the lowest in hybrid dryer. Bioactive properties values were generally greater in control group samples of all cultivars. Considering the entire cultivars and drying systems together, the greatest TPs was observed in open-sun drying and the greatest HMF values were observed in microwave drying. Color, biochemical traits and drying characteristics of windfall and regular apples were generally similar with the literature findings. Significant positive effects were observed in terms of protein content, color characteristics

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and drying times in ultrasound pretreated products. Ultrasound pretreatment is recommended to improve these properties. However, no significant difference was found in terms of bioactive properties and HMF content.

DISCLOSURE STATEMENT

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the article.

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