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Effect of different pre-treatments and storage conditions on some quality parameters of apple chips dried by vacuum combined two side infrared radiation

Farklı ön işlemler ve depo koşullarının vakum destekli çift yönlü infrared radyasyon ile kurutulan elma cipslerinin bazı kalite parametreleri üzerine etkisi

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Abstract

The effect of ultrasound (0, 50, and 100% amplitude), ethanol (0, 50, and 100%), citric acid (0.75%), and their combined application on some quality parameters and microstructure of apple slices dried by novel vacuum combined two-way infrared dryer (275W, 400 mmHg) were investigated. In addition, the changes in quality parameters at 20, 30, and 40°C during 8-month storage were evaluated. The different pretreatments, especially their combinations, had significantly affected the drying time, rehydration rate, color values (L, a*, and b*), browning index, sugar content, 5-hydroxymethylfurfural (HMF), and sensory properties of the apple slices. The increasing ethanol concentration and ultrasound amplitude shortened the drying time from 110 min to 71 min. The high ethanol concentration combined with high ultrasound amplitude resulted in increased rehydration rate and decreased browning index, HMF, and general acceptance. As a result, the combination of ethanol containing (99.9%) 0.75% citric acid and 100% ultrasound amplitude was the best pretreatment method in terms of drying time, color, rehydration rate, browning index, and HMF content of apple chips.*

Keywords: Ethanol, Ultrasound, Apple chips, Infrared drying, Storage.

Öz

Ultrason (%0, 50 ve 100 genlik), etanol (%0, 50 ve 100), sitrik asit (%0.75) ve bunların kombine uygulamalarının vakum destekli çift yönlü infrared kurutucu (275W, 400 mmHg) ile kurutulan elma dilimlerinin bazı kalite parametreleri ve mikro yapısı üzerine etkisi araştırıldı. Ayrıca, 8 aylık depolama süresince 20, 30 ve 40°C'de kalite parametrelerindeki değişimler değerlendirildi. Farklı ön işlemlerin, özellikle de bunların kombinasyonlarının, elma dilimlerinin kuruma süresini, rehidrasyon oranını, renk değerlerini (L, a* ve b*), esmerleşme indeksini, şeker içeriğini, 5-hidroksimetilfurfural (HMF) ve duyusal özelliklerini önemli ölçüde etkilediği tespit edildi. Artan etanol konsantrasyonu ve ultrason genliği kurutma süresini 110 dakikadan 71 dakikaya indirdi. Yüksek ultrason genliği ile birlikte yüksek etanol konsantrasyonu, rehidrasyon oranının artmasına ve esmerleşme indeksi, HMF ve genel beğeninin azalmasına neden oldu. Sonuç olarak, %0.75 sitrik asit içeren saf etanol (%99.9) ile %100 ultrason genliği kombinasyonunun, elma cipslerinin kurutma süresi, renk, rehidrasyon oranı, esmerleşme indeksi ve HMF içeriği açısından en iyi ön işlem yöntemi olduğu tespit edilmiştir.*

Anahtar kelimeler: Etanol, Ultrason, Elma cipsi, İnfrared kurutma, Depolama.

1 Introduction

Apple (*Malus domestica* Borkh.) is extensively cultivated fruit in temperate regions of the world [1]. Apple is consumed as a fresh, juice, jam, marmalade, chips, etc [2]. Interest in fruit chips has continued to grow in recent years. Fruit chips are produced by different drying methods. The conventional methods using hot air have been widely used. However, it has some disadvantages, including long processing time, high temperatures, and consequently high energy consumption, leading to increased production costs and the degradation of heat sensitive nutrients [3]. New techniques and methods for reducing the disadvantages of conventional drying are developed. Novel combined infrared-vacuum drying is a new technique for drying and has some advantages such as energy consumption, time saving, and high product quality when compared to conventional drying [4]. Recently, there have been some reports on the use of vacuum-combined infrared radiation (VCIR) to produce dried fruits and vegetables [4],[5]. However, all drying processes can negatively affect the nutrient content of the raw material [6]. Some pre-treatments that decrease the initial water content or change the fruit tissue structure can be used to reduce the drying time [7]. Ultrasound, high hydrostatic pressure, pulsed electric fields, sugar and ethanol application etc are the examples of pretreatments [8]. Utilizing ethanol for pre-treatment is a straightforward yet effective method that has also been researched for drying [8]. Accordingly, alcohol has the potential to quickly replace water under the influence of ultrasound, thereby significantly improving the food drying process and the quality of the dried food. It is harmless to humans and does not leave any residue after drying [9]. For example, Wang et al. [10] reported a significant reduction in the drying time of scallion slices pretreated using the ethanol solution and these samples also had better rehydration, odor, vitamin C content, and antibacterial effect. In another research, Wang et al. [11]

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declared that the apple slices pretreated with ethanol dried faster than the control samples and drying time was reduced by 45-60% at various drying temperatures (50, 60, 70, and 80°C). Immersion in ethanol combined with ultrasound as pretreatment have recently attracted attention. Ren et al. [12], Zhou et al. [13] and Amanor-Atiemoh et al. [14] utilized the ethanol combined with ultrasound as a pretreatment for drying gingers, scallions and apple slices, respectively. The results showed that the combinations accelerated the dehydration of foodstuffs and caused a decrease in the drying time. In this study, researched the effects of pre-treatments (citric acid, ethanol, ultrasound and their combination) and different storage conditions on some quality parameters of dried apple chips with VCIR.

2 Material and methods

2.1 Application of pretreatments

Fresh apples (*Starking delicious*) obtained from Hakkari, Turkey. Apples were simultaneously peeled and sliced (3 mm thickness) with a manual fruit slicer and then apple slices were pretreated using ethanol and ultrasound. The ratio of apple slices to immersion solutions, amplitude values, and citric acid was selected after preliminary experiments. The use of different ethanol concentrations as immersion solutions and ultrasound amplitude were as follows: absolute ethanol (99.9%) with and without ultrasound treatment (E100 and E100US, respectively), ethanol: distilled water (1:1) with and without ultrasound treatment (E50 and E50US, respectively) and distilled water with and without ultrasound treatment (E0 and E0US). Citric acid (0.75 g/100 ml) was added to all immersion solutions. The apple slices (160±1 g) and immersion solutions (distilled water, distilled water:ethanol (1:1) and ethanol (99.9%)) (640 mL) were placed in a 1000 ml glass beaker at 25°C. Precision scale (AND GF3000, Japan) was used for weighing the samples. Samples were supported with ice packs during pretreatment to keep the temperature constant. The samples were subjected to sonication using a probe connected to a 20 kHz frequency ultrasonic generator (Bandelin Sonopuls, HD 3200, Germany) operating at 200 W power, with selected periods (5 min) and amplitudes (0, 50, and 100%).

2.2 Drying experiment

Novel two-way infrared dryer (Uniterm, Ankara) combined with a vacuum pump (DOA-P730-BN, USA) was used to dry the apple slices (Fig. 1). The novel two-way infrared dryer system consisted of four 250W infrared lamps placed on the ceiling and floor inside the oven. The distance between the samples and lamps was maintained at 12 cm. The sample was dried using 275 W infrared power and 400 mmHg vacuum pressures. All experiments were conducted in five replicates. Fresh apple had 84.41±0.28% (w.b.) moisture content and the drying process was stopped when the moisture content of apple slices reached 4.5-5% (w.b.). The final moisture range of the samples was monitored by drying the samples in an oven. The oven-drying method was used to determine the moisture contents of the samples [15].

2.3 Storage

The 20 g chips were placed into packaging material made of metalized PET (polyethylene terephthalate). Subsequently, all the samples were stored in incubators at 20, 30, and 40°C for an 8-month duration. At 1, 2, 4, 6, and 8 months of storage, five packages from each sample group were removed from the incubators for analysis.

2.4 Color

Brightness (L*), redness (a*), and yellowness (b*) values of samples were measured by a chromo-meter (Konica Minolta CR-400, Japan).

Figure 1. Vacuum combined two side infrared radiation drying.

2.5 Scanning Electron Microscopy (SEM)

Microstructures were observed by Field Emission-SEM (Zeiss Sigma 300 FESEM Oberkochen, Germany). The images of samples coated with gold-palladium were observed under high vacuum at 10 kV at 500 × magnification.

2.6 Rehydration Ratio (RR)

To estimate the rehydration ratio, the apple chips were submerged in pure water at 20°C for 14 h [16]. After removing the excess water with absorbent paper, the rehydrated apple chips were weighed [17]. The RR was defined according to the following equation: RR= Weight of rehydrated apples (g) / Weighet of dried apples (g)

2.7 Extraction and quantification of HMF

The extraction of HMF was conducted following the methods previously described by Bakkalbaşı et al. [18]. A mixture of apple chips (1 g) and 15 mL of 80% methanol was shaken (150 rpm) for 2 h at room temperature and then centrifuged for 10 min at 8000 g at 4°C. The residue was extracted again using 10 mL of 80% methanol. Supernatants were collected and their volume reached 25 mL with 80% methanol. The HMF analysis was conducted utilizing the HPLC system (Shimadzu, Kyoto, Japan). Seperation and identification of HMF content in the apple samples was performed a Symmetry C18 column (250×4.6 mm id, particle size 5 µm) at 25°C. The mobile phase consisted of 2% acetic acid in water (A) and 0.5% acetic acid in a mixture of water and acetonitrile (1:1, v/v; B). A gradient program was as follows: 10% B at 0 min and 20% B at 30 min at a 1.0 mL/min flow rate. The concentration of HMF was determined using the HMF standard (2295.2, Carl Roth, Germany) [19].

2.8 Sugar

The sample (1 g) was extracted with 15 mL of distilled water for 2 hours on an orbital shaker at ambient temperature. After extraction, it was centrifuged at 3600 *g* for 10 minutes. The supernatants were filtered through a 0.45 µm syringe type filter and then, injected into the HPLC system (Shimadzu, Japan) equipped with a refractive index detector (RID-20A, Shimadzu, Japan). Intersil NH2 (4.6 x 250 mm ID, 5 µm) (GL Sciences Inc.,

Tokyo, Japan) column was used with a mobile phase (acetonitrile:water, 80:20 v/v) at an isocratic flow rate of 1.3 ml/min. Detection was made at 25°C. The sugars were identified based on their retention time compared to standards (Sigma-Aldrich Co., St. Louis, USA). The sugar content was demonstrated as g/100 g dried matter and the total sugar amount was calculated by the sum of fructose, glucose, and sucrose [20].

2.9 Browning Index (BI)

The sample (1 g) was placed into a beaker along with 25 mL of distilled water. The content was homogenized at 10000 rpm for 30 seconds, kept at room temperature for 1 h, then centrifuged at 800 × g for 20 minute. The supernatant (10 ml) was mixed with 15 mL of 95% ethanol. The mixture was centrifuged again at 800 × g for 20 minutes. BI was measured at 420 nm by a spectrophotometer (8453, Agilent, USA). Results were demonstrated as absorbance per gram of initial dry matter (Abs/g initial DM) [21].

2.10 Sensory Evaluation

Sensory analysis was conducted with 16 semi-trained panelists. Samples labeled with three-digit random codes were presented to the panelists. The evaluation included assessing the appearance, color, odor, crispness, chewiness, taste, and general acceptance of the dried samples. Each feature was evaluated on a nine-point hedonic scale, with 1 representing extreme dislike and 9 representing extreme like [22].

2.11 Statistical Analysis

The averages and standard deviations (SD) were used to represent the experimental values. The data was analyzed using SPSS 20.0 software for variance analyses, and the Duncan multiple comparison test was used. Significant different was defined at $p<0.05$.

3 Results and discussion

3.1 Effect of pre-treatment on some quality parameters of dried apple chips

Moisture content and drying time of apple chips are given in Table 1. The drying time of samples pre-treated with ethanol or ultrasound was reduced by 3-35% compared to the E0-0US sample. The drying time decreased with increasing ethanol concentration and ultrasound amplitude in pretreatment applications. Feng et al. [9] reported that US+Alcohol pretreatment played a significant role in shortening the drying time in catalytic infrared drying of garlic slices compared to other pretreatments. It was reported that during US+Alcohol pretreatment, the transfer of intracellular water out of the tissue increased due to the removal of more moisture, displacement of gas in the intercellular spaces by alcohol, and more rupture of cell walls and membranes. The samples pre-treated with 100% ethanol had the shortest drying times (71-76 min). This was significantly lower when compared to samples pretreated with 0% and 50% ethanol. A similar situation was observed in dried melon samples. The melons immersed in 100% ethanol solution had lower drying times than samples immersed in 50% ethanol [23]. Santos et al. [24] reported that generally, ethanol and ethanol combined with US pretreatments provided faster drying than the water combined with US pretreatment and control. It was determined that the moisture content of apple chips after drying varied within a narrow range (4.56 - 4.92%). For moisture content, the difference among the ultrasound powers at 100% ethanol concentration, and ethanol concentrations at 0% and 50% ultrasound amplitude were significant ($p<0.05$).

The RR of chips changed between 3.39 and 6.36 ($p<0.05$) (Table 1). RR increased with an increase in ultrasound amplitude. This can be explained by increased pore formation due to cavitation [25]. Increasing RR was observed in pre-treated samples by high ethanol concentration, particularly when combined with US. Dadan and Nowacka. [26] reported similar results in carrot sample pre-treated with only ethanol (96%) or ethanol combined with US. This was attributed to increased plant cell resistance to shrinkage during drying due to more ethanol entering the tissue [26].

Color parameters of the samples were summarized in Table 1. While L* values of dried samples were lower than the L* values of fresh apples, a* and b* values were higher. Similar findings were recorded by da Cunha et al. [23] for convectively dried melon sample. Increase in ultrasound amplitude without ethanol application decreased L* values ($p>0.05$) but a* ($p>0.05$) and b* ($p<0.05$) values increased. However, the L* value of apple chips increased with increasing ultrasound amplitude used with ethanol, and the a* and b* values decreased. It was observed that the positive effect of ethanol on color was stronger and suppressed the negative effect of ultrasound on color. In fact, the use of these two applications together may have created a synergistic effect and strengthened the effect of ethanol. The ethanol application had a positive effect on increasing the lightness and decreasing the redness of apple chips. This positive effect increased as the ethanol content increased from 50% to 100%. The difference between the ethanol concentrations at the same ultrasound amplitude was significant for L* and a* ($p<0.05$). Similar findings were reported by Ren et al. [12] for Chinese ginger and Feng et al. [9] for garlic. It may be due to the fact that the alcohol dissolved the pigments. In addition, ultrasound application increased the decolorization effect of alcohol [9].

The images of scanning electron microscopy of the apple chips samples were presented in Figure 2. The sample pretreated by water and ethanol combined with ultrasound exhibited microstructures fragmented with numerous surface holes. However, the E50-100US showed lower porosity. Additionally, the density of the holes in the cells of the sample treated with E100-100US is significantly higher compared to the sample treated with E0-100US. The increase in ethanol concentration caused the cells to become more compact and an increase in structural changes within the apple tissue. These changes led to improved drying and rehydration properties of the chips. It was also found that the E100-100US sample had the highest rehydration rate. In the E50-100US samples (Figure 2e), several pits in the membranes was deteriored, some collapses were occured and microchannels had decreased compared to the E50-0US (Figure 2d). The collapses could be due to ultrasound-related cavitation during pretreatment [28].

The drying after ultrasound and ethanol pretreatment caused a decrease in sugar content when compared to fresh sample (Table 2). While the sucrose in the sample decreased with increasing ultrasound amplitude, the glucose content of the samples pretreated with 50% ethanol ($p<0.05$) and the fructose content of all samples increased ($p>0.05$). These may be related to the conversion of sucrose to invert sugars. The total sugar content of the samples decreased slightly with increasing ultrasound amplitude. It may be due to the participation of invert sugars in HMF formation. The content of fructose, sucrose, and total sugar in the E50 samples was lower than those of the E0 and E100 samples. The results indicated that

50% ethanol can be a good solvent for fructose and sucrose. Giannoccaro et al. [29] reported that the extracts prepared with 10 and 50% ethanol concentration among the different ethanol concentrations (10, 50, and 80%) had the highest total sugar amounts.

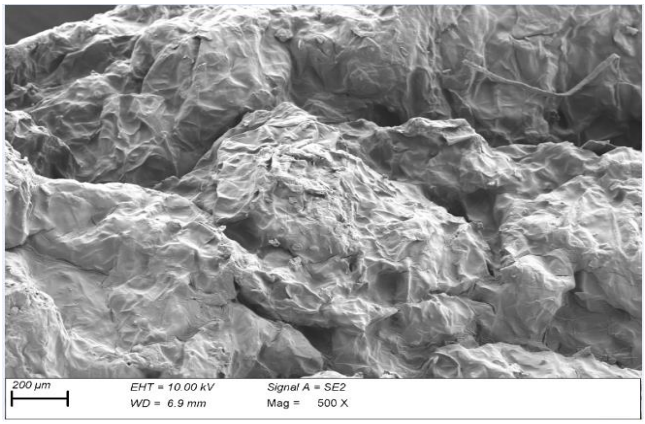
HMF does not find naturally in food products. It is formed as a result of Maillard reactions under the influence of heat treatment and other factors (concentration of reducing sugar, type of sugar used, storage time and temperature, etc.). The amount of HMF varies even among the same type of food items [30]. HMF chromatograms of standard (a) and samples (b) are given in Figure 3. BI value and HMF content of apple chips were shown in Table 2. Their values ranged from 0.036-0.103 Abs/g initial DM and 118.22-354.11 mg/kg DM, respectively. The HMF content of apple chips was similar or higher than the findings of Murkovic and Pichler. [31] for dried apple (80 ppm), dried pineapple (280 ppm), and dried apricot (30–780 ppm). The increase in ultrasound amplitude in E0 samples increased the BI value and HMF content of the dried products without ethanol. At the same time, L* decreased while a* and b* values increased in these samples. However, when the use of ethanol as dipping solution, HMF contents and BI values decreased with increasing ultrasound amplitude. In samples prepared with ultrasound amplitudes of 0% and 50%, no steady change was detected with increased concentration of ethanol, and 50% ethanol had highest HMF content and BI values. Longer exposure of samples E0 and E50 to infrared radiation due to the longer drying times may have resulted in higher HMF and BI values. The samples pretreated with 100% ethanol had significantly lower HMF content and BI value than those of 0% and 50% ethanol ($p<0.05$). The most remarkable result was found in the E100-100US sample, which contained the lowest HMF (118.22 mg kg^{-1} DM) and BI value (0.036 Abs/g initial DM). Kayacan et al. [32] determined the amount of HMF in persimmon dried with infrared as 12.13 mg/kg DM. HMF contents of pears dried with vacuum combined infrared radiation were found as 0-132.94 mg/kg DM [4]. In our study, the HMF levels in samples pretreated with 100% ethanol concentration were close to those found by Topuz et al [4]. Deng et al. [33] reported that BI values in red peppers dried at different temperatures (60-80°C) by infrared radiation-assisted hot air-drying ranged between 0.32-0.80 Abs/g dry weight.

Table 3 shows the sensory evaluation scores obtained from the sensory panel. Although the 100% ethanol aplications gave the highest L* values, It received the lowest appearance and color scores. In this case, it is concluded that the panelists do not prefer lighter-colored chips. Panelists reported that all samples had a typical apple off-odor that was not detected in samples. Increasing the ultrasound amplitude from 0 to 100% decreased the general acceptance of all dried apples. The samples pretreated with the 50% ethanol without ultrasound had the best crispness, chewiness, and general acceptability scores. The E50-0US sample had the lower L* value and the highest browning index, and the HMF value compared to all other samples. Therefore, it can be concluded that, as highlighted before, panelists prefer darker-colored chips. The sun-dried fruit consumption habits of consumers in Turkey may have caused them to prefer darker coloured fruits.

Table 1. Drying time, moisture, rehydration ratio, and color values of apple chips.

Samples	Drying Time (min)	Moisture (%)	Rehydration Ratio	L*	a*	b*
Fresh*	-	84.41±0.28	-	74.37±0.82	0.39±0.56	18.00±1.55
E0-0US*	110	$4.73±0.07^{bcA1}$	$4.59±0.45^{bcA2}$	$62.67±3.00^{abA1}$	$6.47±1.69^{cdA2}$	$29.25±6.42^{aA1}$
E0-50US	106	$4.78±0.08^{cdA12}$	$5.16±0.59^{cA2}$	$61.99±4.34^{aA1}$	$6.64±0.67^{dA2}$	$33.29±1.99^{bAB1}$
E0-100US	102	$4.92±0.02^{eA1}$	$5.36±0.37^{cA12}$	$61.47±3.04^{aA1}$	$6.69±2.04^{dA3}$	$34.16±3.10^{bcB1}$
E50-0US	106	$4.92±0.01^{eA2}$	$3.39±0.29^{aA1}$	$62.64±2.79^{abA1}$	$7.67±1.03^{dB2}$	$37.82±3.31^{cB2}$
E50-50US	104	$4.92±0.02^{eA2}$	$3.79±0.09^{abA1}$	$63.79±5.04^{abA1}$	$5.81±2.91^{cdAB2}$	$35.24±3.61^{bcAB1}$
E50-100US	98	$4.79±0.07^{cdeA1}$	$3.94±0.05^{abA1}$	$65.44±3.78^{bcA2}$	$4.42±2.38^{bcA2}$	$34.06±3.26^{bcA1}$
E100-0US	76	$4.56±0.05^{aA1}$	$5.15±0.34^{cA2}$	$67.49±2.85^{cdA2}$	$3.48±2.54^{abA1}$	$34.33±4.82^{bcA2}$
E100-50US	74	$4.64±0.06^{abA1}$	$5.38±0.00^{cA2}$	$70.12±2.96^{deAB2}$	$2.97±1.69^{abA1}$	$34.25±2.07^{bcA1}$
E100-100US	71	$4.89±0.04^{deB1}$	$6.36±0.86^{dA2}$	$71.63±3.39^{eB3}$	$1.74±2.25^{aA1}$	$33.46±4.44^{bA1}$

Values are presented as mean±SD. Lowercase letters show the difference between samples in the same column according to the Duncan multiple comparison test, uppercase letters show the difference between the ultrasound amplitudes of the samples to which the same ethanol concentration was applied, and the numbers show the difference between the ethanol concentrations of the samples to which the same ultrasound amplitude was applied ($p < 0.05$). * The data about samples were reported previously study [27].



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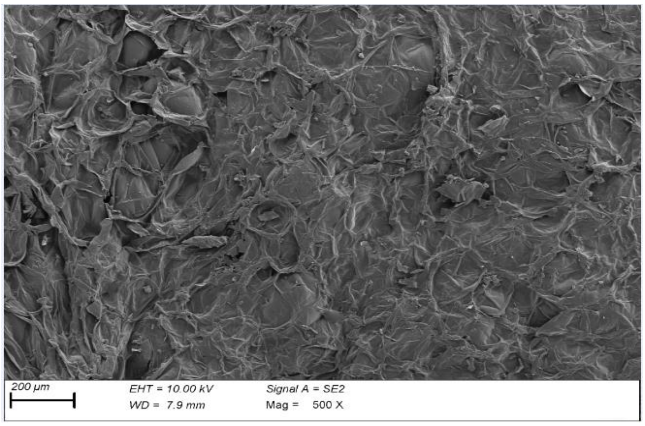

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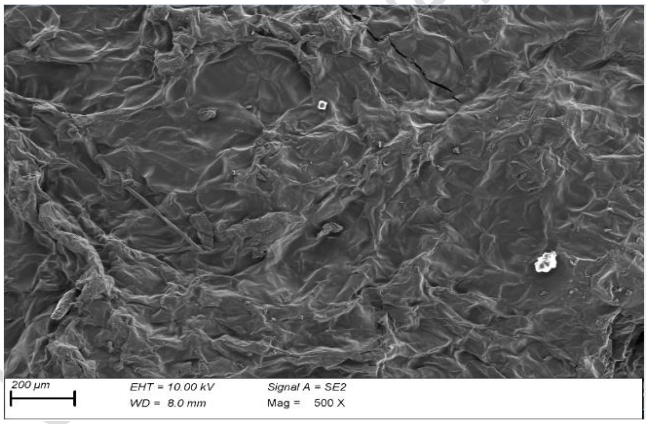

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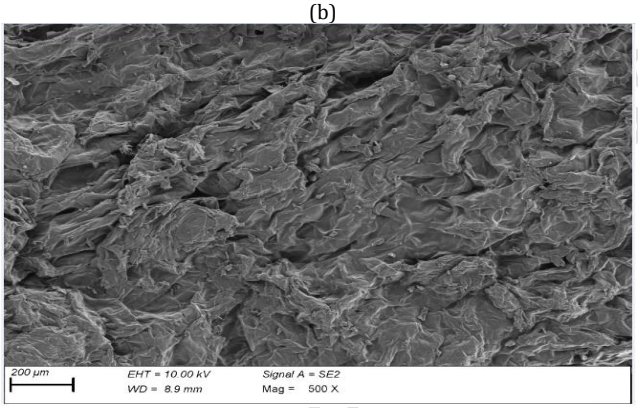

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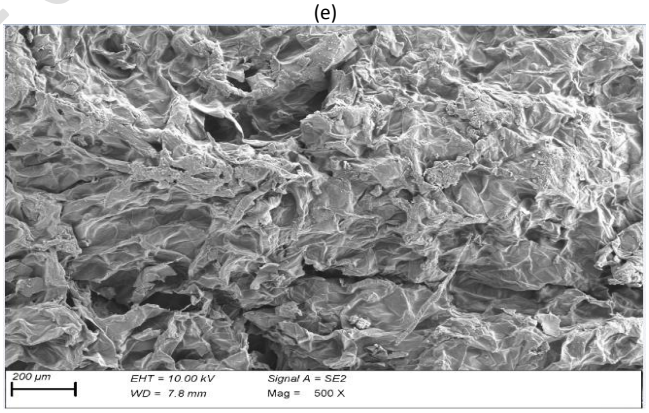

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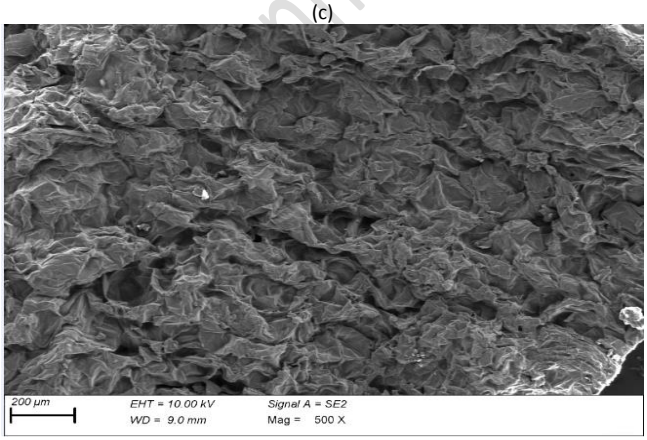

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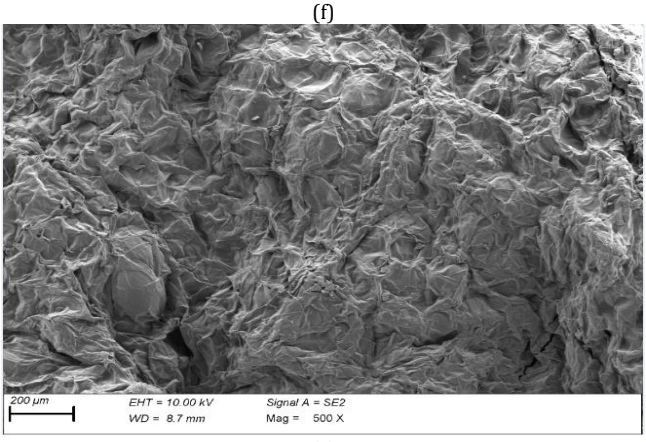


(g)

Figure 2. The SEM images of samples (a*- fresh; b*- E0-0US; c- E0-100US; d- E50-0US; e- E50-100US; f- E100-0US; g- E100-100US). * The data about samples were reported previously study [27].

Table 2. Sugar content, HMF, and browning index of apple chips.

Samples	Fructose (g/100 g DM)	Glucose (g/100g DM)	Sucrose (g/100 g DM)	Total Sugar (g/100 g DM)	Browning index (Abs/g initial DM)	HMF (mg/kg DM)
Fresh*	43.63±1.12	24.02±1.73	14.71±1.23	82.36±1.63	0.001±0.00	-
E0-0US*	35.86±1.38^{abA2}	19.12±0.06^{cdB1}	11.47±0.36^{bA2}	66.46±1.68^{bA2}	0.077±0.01^{bcdA12}	301.44±3.88^{bA2}
E0-50US	36.56±1.87^{abcA12}	17.16±0.95^{abAB1}	8.22±4.16^{abA1}	61.95±3.24^{abA1}	0.079±0.02^{cdA2}	313.00±2.93^{bA2}
E0-100US	37.31±1.70^{abcA1}	17.01±0.48^{abA2}	7.05±0.56^{aA1}	61.38±2.76^{abA1}	0.080±0.02^{cdA1}	320.01±88.00^{bA2}
E50-0US	33.03±0.49^{aA1}	17.29±0.15^{abcA1}	7.43±0.00^{aB1}	57.76±0.15^{aA1}	0.103±0.03^{dA2}	354.11±2.82^{bA3}
E50-50US	33.08±0.94^{aA1}	18.28±0.03^{bcdB1}	6.05±0.00^{aAB1}	57.42±0.97^{aA1}	0.082±0.00^{dA2}	345.78±42.87^{bA2}
E50-100US	33.49±1.95^{aA1}	19.34±0.24^{dC3}	4.57±1.14^{aA1}	57.41±2.84^{aA1}	0.077±0.01^{bcdA1}	300.87±0.16^{bA2}
E100-0US	38.41±0.00^{bcA3}	17.55±1.48^{abcdA1}	7.45±0.41^{aA1}	63.42±1.90^{abA2}	0.043±0.00^{abcA1}	129.06±22.01^{aA1}
E100-50US	39.83±2.14^{bcA2}	16.46±1.42^{abA1}	6.99±0.00^{aA1}	63.30±3.57^{abA1}	0.041±0.01^{abA1}	127.24±2.82^{aA1}
E100-100US	40.49±3.49^{cA1}	15.85±0.00^{aA1}	6.01±1.77^{aA1}	62.37±5.27^{abA1}	0.036±0.01^{aA1}	118.22±21.13^{aA1}

Values are presented as mean±SD. Lowercase letters show the difference between samples in the same column according to the Duncan multiple comparison test, uppercase letters show the difference between the ultrasound amplitudes of the samples to which the same ethanol concentration was applied, and the numbers show the difference between the ethanol concentrations of the samples to which the same ultrasound amplitude was applied ($p<0.05$). * The data about samples were reported previously study [27].

Table 3. Sensory evaluation results of dried apple chips.

Samples	Appearance	Color	Odor	Crispness	Chewiness	Taste	General Acceptance
E0-0US	6.84±1.86^{bA1}	7.38±1.19^{cB2}	6.76±1.36^{aA1}	7.30±1.65^{bcA1}	7.07±2.06^{abcA1}	7.61±1.32^{bA1}	7.53±1.05^{bcB1}
E0-50US	5.00±2.51^{abA12}	5.46±1.98^{abB12}	6.69±1.70^{aA1}	7.23±1.73^{bcA1}	6.84±1.57^{abcA1}	7.07±1.60^{abA1}	6.76±1.73^{abcAB1}
E0-100US	6.07±2.21^{abA1}	7.00±1.41^{bcA1}	6.61±1.50^{aA1}	5.84±2.23^{aA1}	6.07±2.21^{aA1}	6.61±1.38^{abA12}	6.23±1.64^{aA1}
E50-0US	6.69±1.79^{abA1}	7.23±1.64^{cA2}	6.84±1.57^{aA1}	8.38±0.76^{cB2}	8.30±0.75^{cB1}	7.46±1.05^{bB1}	7.69±0.85^{cB1}
E50-50US	6.76±1.58^{bA2}	7.00±1.68^{bcA2}	6.38±1.70^{aA1}	7.23±1.23^{bcA1}	7.07±1.84^{abcA1}	7.38±1.26^{abB1}	7.15±1.28^{abcAB1}
E50-100US	6.30±1.60^{abA1}	6.46±1.50^{abcA1}	6.84±1.46^{aA1}	6.76±1.78^{abA12}	6.61±1.55^{abA1}	6.30±1.37^{aA1}	6.46±0.96^{abA1}
E100-0US	5.92±2.21^{abA1}	5.38±2.21^{abA1}	6.69±1.60^{aA1}	8.07±1.25^{bcA12}	7.92±1.32^{bcA1}	7.69±1.10^{bA1}	7.53±0.96^{bcA1}
E100-50US	4.76±2.68^{aA1}	5.00±2.51^{aA1}	6.92±1.38^{aA1}	8.07±1.65^{bcA1}	8.15±1.34^{cA1}	7.61±1.32^{bA1}	7.46±1.12^{bcA1}
E100-100US	5.61±2.72^{abA1}	5.76±2.61^{abcA1}	7.15±1.34^{aA1}	7.69±1.93^{bcA2}	7.38±1.98^{abcA1}	7.53±1.26^{bA2}	7.07±1.44^{abcA1}

Value are presented as mean±SD. Lowercase letters show the difference between samples in the same column according to the Duncan multiple comparison test, uppercase letters show the difference between the ultrasound amplitudes of the samples to which the same ethanol concentration was applied, and the numbers show the difference between the ethanol concentrations of the samples to which the same ultrasound amplitude was applied ($p<0.05$).

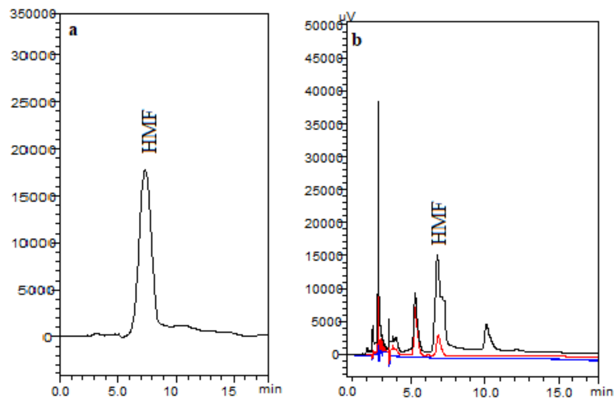


Figure 3. HMF chromatogram of standard (a) and samples (b).

3.2 Influence of storing conditions on some quality parameters of apple chips

The E50-0US sample, which had the highest general acceptance, was used for evaluation of the effect of storage time and temperature. Apple chips samples were stored at 20, 30, and 40°C for eight months. Due to their low equilibrium moisture content and hygroscopic properties, dried products can absorb moisture from the surrounding atmosphere, depending on the moisture permeability of the packaging [34]. The moisture in the packaging is due to the moisture permeability of packaging material. Therefore, moisture contents of samples significantly increased at 20°C and 30°C during storage ($p<0.05$) (Fig. 4). Although the moisture content slightly increased at 40°C during four months of storage, it significantly decreased after the 4th month ($p<0.05$). Cichowska et al. [35] reported a similar result for dried apple during storage at 45°C. In our study, the differences among storage temperatures for moisture content in the 6th and 8th months were significant ($p<0.05$).

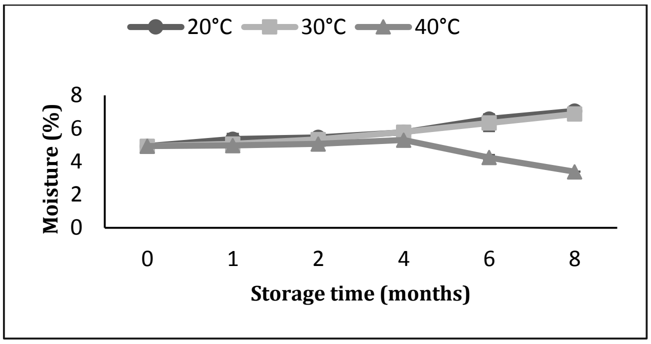
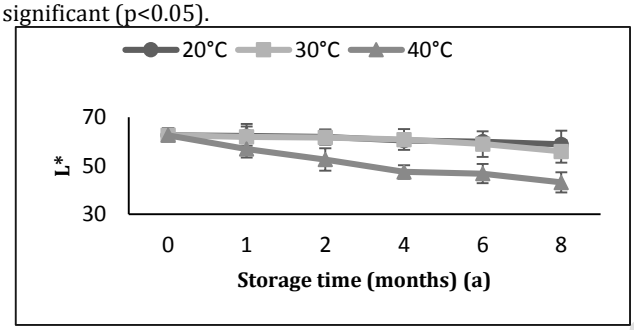
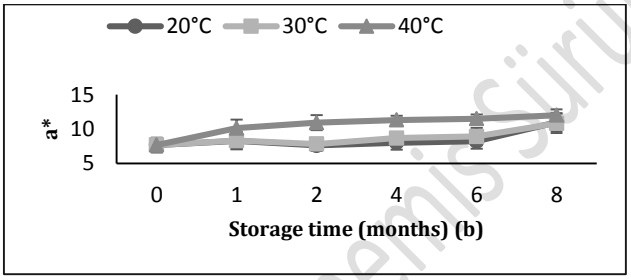


Figure 4. Moisture content of apple chips stored at different time and temperatures.

L* and b* values of samples decreased during 8 months of storage. However, a steady increase in a*, BI, and HMF was observed during the storage of apple chips, (Fig. 5, 6, and 7

respectively). Similar findings for L*, a*, b*, and HMF were reported by Turgut and Topuz. [36] in dried kumquat slices during 4 months of storage. When comparing all the storage temperatures, the most important differences for L*, a*, b*, HMF, and BI values were detected at the highest temperature (40°C). The HMF content, color (L*, a*, and b*), and BI values were significantly lower at 20 and 30°C compared to 40°C during storage ($p<0.05$). While HMF contents, a* and b* values were significantly changed at all temperatures during storage ($p<0.05$), there were significantly changes in L* and BI values only at 30 and 40°C ($p<0.05$). HMF content in the initially sample was high, and it gradually increased with temperature during the storage. The fructose, sucrose, and total sugars of stored apple chips decreased significantly from initial values of 33.03, 7.43, and 57.76 g/100 g DM to 23.56-31.40, 2.94-3.91 and 43.66-53.10 g/100 g DM, respectively ($p<0.05$) (Table 4). However, glucose content slightly increased after storage at 20 and 30°C and it has not changed at 40°C. This situation may be due to the moisture gain and the use of sugar in browning reactions [37]. The difference among storage temperatures in terms of fructose and total sugar content was statistically significant ($p<0.05$).





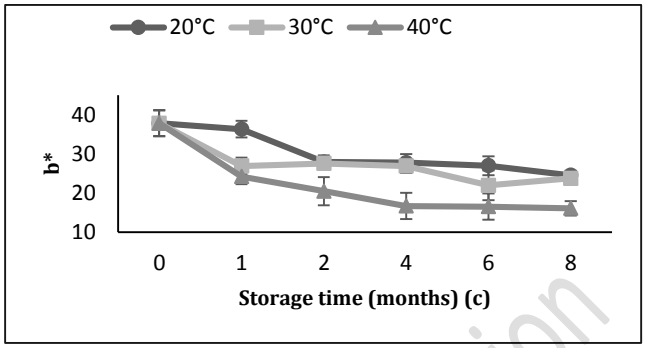


Figure 5. L* a* and b* values of stored apple chips (a, b, and c).

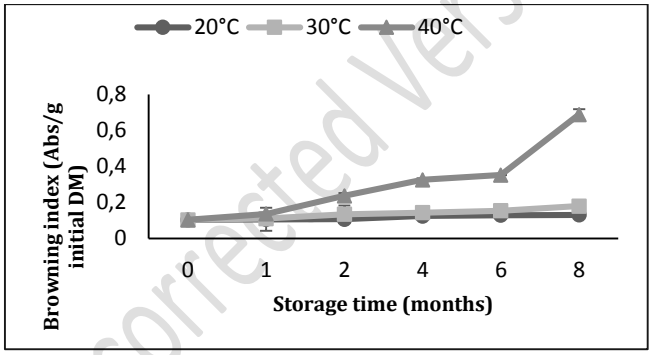


Figure 6. Browning index of stored apple chips.

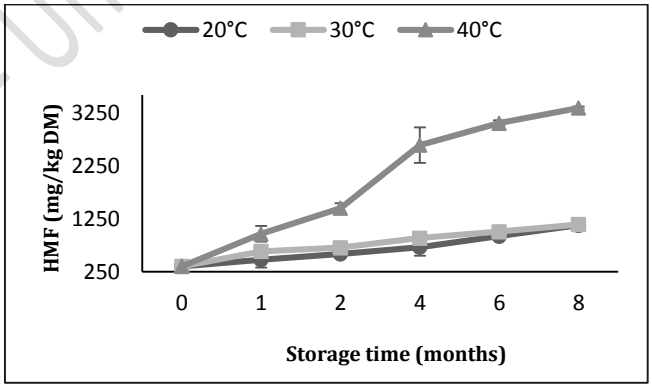


Figure 7. HMF content of stored apple chips.

Table 4. Sugar content of stored apple chips.

	Time (month)	20°C	30°C	40°C
Fructose	0	33.03±0.49	33.03±0.49	33.03±0.49
	8	31.40±0.00^{b}	30.57±0.61^{b}	23.56±0.15^{a}
Glucose	0	17.29±0.15	17.29±0.15	17.29±0.15
	8	18.31±0.96^{a}	17.81±0.10^{a}	17.15±0.37^{a}
Sucrose	0	7.43±0.00	7.43±0.00	7.43±0.00
	8	3.38±0.52^{a}	3.91±0.00^{a}	2.94±0.62^{a}
Total sugar	0	57.76±0.15	57.76±0.15	57.76±0.15
	8	53.10±1.49^{b}	52.31±0.51^{b}	43.66±0.40^{a}

Value are presented as mean±SD. According to Duncan multiple comparison test, lowercase letters show difference among samples in the same row ($p<0.05$).

4 Conclusions

In summary, the ultrasound and ethanol combination as pretreatment significantly reduced the drying time of chips in VCIR drying. The pretreatment method combining ultrasound and ethanol can be used for time saving and high quality product in VCIR drying. High ethanol concentration and ultrasound combination were better than only ultrasound pretreatments in terms of rehydration ratio, HMF, color, and BI values. However, it had a lower general acceptance value. While lightness and sugar contents were decreased during storage, the HMF content, a*, and BI values of apple chips increased. Color values, sugars, and HMF contents of apple chips were more stable at low temperature storage. Further investigation is necessary to understand the influences of different combined pretreatment applications and storage conditions on other quality parameters of apple chips.

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6 Author contributions

Author 1, Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft. Author 2, Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Writing – review & editing.

7 Ethics committee approval and conflict of interest

"Ethics committee permission is not required for the article prepared". "There is no conflict of interest with any person/institution in the article prepared".

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