COMPARISON OF A NOVEL VACUUM-COMBINED INFRARED AND HOT-AIR CONVECTION METHODS FOR DRYING OF DEVECI (PYRUS COMMUNIS L.) PEAR SLICES

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Abstract— **In this study, the quality characteristics of pear slices dried in vacuum-combined infrared dryer equipped with a two-way infrared heating (100-300 W infrared power) and convectional dryer (40-70 °C) were comparatively investigated. Increasing infrared power in vacuum-combined infrared dryer decreased the drying time. However, the differences between vacuum pressures (100 mmHg and 250 mmHg) were generally negligible. Drying process at 200 and 300 W IP under vacuum was approximately 2- and 2.5-times shorter than conventionally drying at 55 and 70 °C, respectively. Although a very low amount of HMF in dried pear slices by the conventional dryer was detected only at 70 °C after 300 min, high amounts of HMF was detected at 300 W after 120 minutes. The rehydration rate of pear slice dried with vacuum-combined infrared dryer was higher than those of pear slice dried with conventional dryer. Syringic, chlorogenic and ellagic acids were identified in dried pear samples. Chlorogenic acid was found to be the most among phenolic compounds in dried pears. While the ellagic acid was not detected in fresh pear, dried pears had ellagic acid content (8.14-16.93 mg/kg d.m.). It was found that total phenolic content, ABTS and DPPH values of dried pears by vacuum-combined infrared dryer was lower than those of dried sample by conventional dryer. The pear slices dried at 300W and 250 mmHg had the highest sensory scores. The results show that the vacuum-combined infrared drying provided a shorter drying time and better sensory quality for dried pear compared to conventional drying.**

Keywords— **Drying process, HMF, Quality, Phenolic compounds, Vacuum pressure.**

I. INTRODUCTION

Pear (Pyrus spp.) with more than 6000 varieties is one of the most widely consumed fruits. In 2018, over 23 million tons of pear were harvested worldwide (FAO, 2019). Pear is commonly consumed as fresh and dried fruit. Dried pear can be used as raw materials and additives (fruit ice cream, yoghurt, cereals, bakery products) in the food industry (Özaydin and Özçelik, 2016). High nutritional content, easy packaging, transportation and storage of dried product are the advantages of drying agricultural products. However, food drying and dewatering is a very energy-intensive process. Energy and time efficiency is considered one of the most significant design and operation parameters in food processing (Adak *et al*., 2017). The hot-air drying is a widely-applied drying technique because of its simple implementation, low requirements for investment and operating costs. However, this technique has high thermal energy requirements with a long drying time, which may change the dried product in an undesirable manner. In recent years, hybrid drying systems such as ultrasonic-microwave, microwave-vacuum, infrared-vacuum, ultrasonic-infrared-vacuum and solar infrared have been used due to their increased evaporation rate and reduced drying time and temperature (Jahanbakhshi *et al*., 2020). Infrared drying has been a widely applied alternative for drying fruits and vegetables (Ashtiani *et al*., 2017). Infrared radiation is defined as a technique that can transfer heat energy as electromagnetic waves. Medium (2-4 µm) and short-infrared (0.6-2.0 µm) wavelength were generally used for drying of food samples (Türker and İşleroğlu, 2017). There are some advantages of infrared dryers compared to conventional dryers. These advantages can be listed as rapid energy transfer, shortening the drying time, energy saving and homogeneous heat distribution (Wang and Sheng, 2006). However, there is a possibility of partial burning or browning in the product because of the fast-heating rate during infrared drying. Therefore, the infrared power and distance between the product and the infrared source and drying time must be carefully adjusted to obtain a higher quality dry product (Guo *et al*., 2020). On the other hand, infrared technology can be combined with other technique in food drying. Especially the vacuum is used successfully in combination with infrared technology. Vacuum-combined infrared drying combines the advantages of both techniques such as water evaporation at lower temperature, oxygen-free drying zone, rapid mass and energy transfer and improved energy efficiency. Therefore, vacuum-combined infrared drying provides low-cost and better-quality product (Salehi and Kashaninejad, 2018). It has been determined that vacuum-combined infrared dryer improves the pore structure of dried product and are dried 8-10 times faster than conventional dryers (Leonard *et al*., 2008; Kouchakzadeh and Haghighi, 2011). Recently, vacuum-combined infrared drying has been studied for drying of fruits and vegetables like lemon, orange, onion, etc. (Bozkir 2020; Mongpraneet *et al*., 2002; Salehi and Kashaninejad, 2018). However, there is no study on drying the pear with vacuum-combined infrared dryer. In this study, pear slices were dried in a vacuum-combined infrared dryer and a conventional dryer. The two drying techniques were compared in terms of drying time, product quality and bioactive characteristics of pear slices.

II. METHODS

Deveci pears (Pyrus communis L.) were harvested in August 2019 from Van City, Turkey. Harvested pears were immediately transferred to the laboratory. After washing, they were kept in a refrigerator at +4 ºC until drying experiments. The initial moisture content of the samples was determined by drying in an oven (Memmert, UN55, Germany) at 105°C for 6 h. The average initial moisture content of Deveci pear was found as 83.45% (w.b.).

After drying process, physical analysis (color and rehydration ratio) of the dried pear samples were done immediately. The dried samples were kept in polyethylene packages at −24°C until the chemical analyses were carried out.

Drying process were performed with a vacuum-combined infrared dryer and convectional dryer. All drying trials were done in 5 repetitions.

Vacuum-combined infrared drying: For more effective drying process, two-way infrared heating system was used. Infrared dryer has four 250 W infrared lamps placed on both the ceiling and the floor inside the oven. In addition, it was equipped with vacuum pump (DOAP730-BN, Pall life science, USA). Perforated steel racks were used inside the dryer. The distance between the slices and the lamps was kept at 12 cm. Peeled and sliced (5 mm thick) pear with a manual fruit slicer (Hex, İstanbul) were used for drying experiments. The pear slices (250 ± 2.00 g) were placed as a single layer on the perforated rack and then dried at 3 different infrared power (IP) (100, 200 and 300 W) and 2 different vacuum pressures (100 and 250 mmHg). The instant temperature during the drying process was followed by a thermocouple placed in the dryer. Drying temperatures corresponding to 100, 200 and 300 W were 40, 55 and 70 ºC, respectively.

Convectional drying: Convectional drying was also done at 40, 55 and 70 ºC in a convection oven (OSCC 61, Öztiryakiler, Turkey). Drying was carried out at the 2nd fan speed in the convection dryer with 5 different fan speeds (1: lowest, 5: highest).

For detection of weight loss during drying, the weights of the pear slices were measured every hour for 100W and every 15 minutes for 200 and 300 W. The final drying times of pear slices at 100, 200 and 300 W were recorded as 600, 195 and 120 minutes, respectively. The weights of the pear slices during convectional drying were measured every hour at 40, 55 and 70 ºC. The final drying times in convectional drying were 600, 390 and 300 minutes, respectively. The drying curves (moisture value vs. drying time) were drown and analyzed.

RR was determined according to Xiaoyong *et al*. (2018) with some modifications. 2 grams of dried pear slices were immersed in 16 mL distilled water, taken out after 24 h. After immersion, the rehydrated pear pieces were weighed. RR was calculated according to the sample weight after rehydration divided by sample weight before rehydration. pH and titratable acidity were determined according to the methods given by AOAC (2003).

L* (brightness, darkness), a* (redness, greenness) and b* (yellowness, blueness) values of the pear slices were measured with the Minolta CR 400 (Tokyo, Japan).

Methanolic extracts of dried and fresh pear slices were prepared for the using in HMF, phenolic content, DPPH and ABTS analysis. Methanolic extracts were prepared according to Bakkalbaşı *et al*. (2013) with some modifications. 5.0 g fresh or 0.5 g dried sample were mixed with 10 mL methanol. The mixture was homogenized at 12000 rpm for 10 seconds by a tissue homogenizer (621.11.001, Isolab, China) and then shaken on an orbital shaker (OS-3000, JEIO TECH, Korea) for 2 hours in the dark at room temperature. It was centrifuged at 8000 g for 10 minutes at 10 ºC. After centrifugation, the supernatant was transferred into an amber bottle. The same procedure was repeated for 2 times using the residue. The supernatants were collected and adjusted to 25 ml. It was stored in an amber bottle at -24 °C until analysis.

TPC was determined by the Folin Cicalteu method (Singleton and Rossi, 1965). Results were expressed as mg gallic acid equivalent per kg sample (dry matter basis) (mg GAE/kg d.m).

DPPH and ABTS assays were determined according to Pyo *et al*. (2004) and Re *et al*. (1999), respectively. The results were expressed as Trolox equivalent antioxidant capacity (mmol TE/g d.m).

Chromatographic analyses were performed with HPLC system (Shimadzu, Kyoto, Japan) that consists of a LC20 AD gradient pump, a Rheodyne 7725i valve furnished with 20 µl loop, a SPD-M20A photodiode array detector, CTO-10AS VP column oven, DGU-14A degasser, and a SCL-10A system controller. Phenolic compounds and HMF assays were made according to Colaric *et al.* (2005) method with slight modifications. Methanolic extracts were filtered through a 0.45 µm PVDF syringe driven filter (Millipore, Bedford, USA) and analyzed by HPLC. Separation of components was carried out using a Waters

Symmetry C18 (250 × 4.6 mm id, particle size 5 µm) column (Waters, USA) at 25 °C. Mobile phase A is 2% acetic acid (v/v) in water and Mobile phase B is water: acetonitrile (1:1, v/v; B). The gradient program was as follows: 0 min 10% B; 30 min 20% B; 60 min 45% B. Detection was made at 276 nm for HMF, 280 nm and 320 nm for phenolic acids, 360 nm for flavanols. The compounds appearing in chromatograms were identified according to retention times and spectral data by comparison with standards.

Sugar content analysis was made according to Hamzaoğlu *et al.* (2018) method with some modifications. For dried pears, 0.5 g of sample and 5ml distilled water was mixed into a tube and the tube was kept for 12 h in dark at room temperature. Distilled water (15 ml) was added in the same tube after 12 h. For fresh pears, sample (2.5 g) was mixed with 25 ml of distilled water. The aqueous mixture in the tube was homogenized at 10.000 rpm for 10 seconds and then shaken at 180 rpm for 1 hour. The mixture was centrifuged for 10 minutes at 3600 g and then filtrated with a 0.45 μm PVDF syringe filter prior to HPLC analysis. Chromatographic analyses were performed with HPLC system (Shimadzu, Kyoto, Japan). The HPLC system consisted of a refractive index (RI) detector (RID-20A, Japan). The eluent was water: acetonitrile (1:4 v/v) with a flow rate of 1.3 mL/min. The separation was performed using isocratic elution and Intersil NH2 column (250 × 4.6 mm id, particle size 5 μm) at 25 ºC. The compounds appearing in chromatograms were identified according to retention times and spectral data by comparison with standards.

Sensory evaluation of the dried samples was made according to Stokes *et al.* (2017) with some modifications. It was carried out by semi-trained 8 males and 7 female panelists. Samples were evaluated using a 9-degree hedonic scale. The panelists were asked to evaluate the samples according to the scales of color, odor, appearance, degree of hardness, hardness appreciation, chewiness, flavor and general taste (1= extremely disliked, 9= extremely liked).

All experimental values were expressed as mean ± SD. In this study, a 3x2 factorial trial design was used. Analysis of the data was carried out using ANOVA (SPSS 20 program, IBM, USA). Differences between means were tested using Duncan's multiple range tests at $p< 0.05$.

III. RESULTS

Drying curves of pear slices dried in the vacuum-combined infrared dryer and the conventional dryer are given in Fig. 1a and 1b, respectively. The moisture content of pear slices rapidly reduced at the beginning and then slowly decreased with increasing drying time. In the last stage of drying, the change in the moisture content was insignificant, and the drying process was terminated when the moisture content fell below 12%. The final moisture values of the slices dried in vacuum-combined infrared and conventional dryers were ranged from 10.08 to 11.79 % and 7.80 to 11.22%, respectively. IP has a significant effect on moisture values of the dried pear slices during drying process ($p<0.05$). As expected, the final drying time of samples was also reduced with increasing IP. The moisture content of the jujube samples during drying process was also significantly affected by changes in IP (62, 88 and 125 W) (Doymaz *et al*., 2016). The moisture values of the pear slices dried under high vacuum pressure (250 mmHg) at the same IP were slightly lower than those of dried under low vacuum pressure (100 mmHg). The difference between the vacuum pressures was not found to be statistically significant ($p>0.05$). Wei-Cui *et al.* (2004) determined that the drying rate of onion was slightly affected by vacuum pressure. Our results indicated that the drying times of

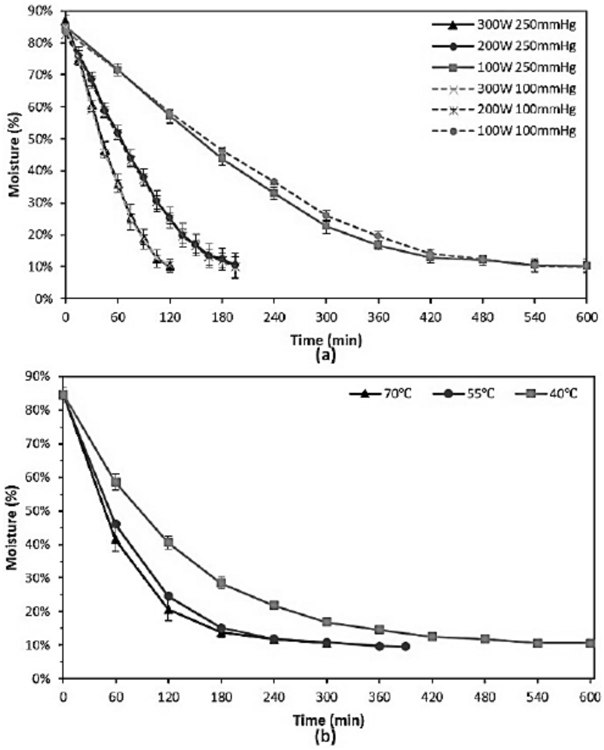

Fig. 1. Drying curves of dried pear slices, (a) drying curves of pear slices dried under 100, 200 and 300 W IP at 250 mmHg vacuum pressure, drying curves of pear slices dried under 100, 200 and 300 W IP at 100 mmHg vacuum pressure, respectively, (b) drying curves of pear slices dried by convectional dryer at 70, 55 and 40 ºC.

pear slices in the vacuum-combined infrared drier at 200 and 300 W were shorter than sample dried in convectional drier at 55 and 70 °C. Pear slices dried at 200 and 300 W IP have approximately 2 and 2.5 times shorter drying time when compare to sample dried in conventional drier at 55 and 70 °C, respectively.

The color is one of the most important factors to influence the customer buying decision. The color values (L*, a* and b*) of dried pear slices are given in Fig. 2. The L*, a* and b* values of fresh pear were found 74.25, -1.36 and 12.67, respectively. For both drying methods, while L* values during drying process were decreased, a* and b* values were increased. As the IP and temperature increased, the changes in product color values increased. L*, a* and b* values of the dried samples ranged from 45.57 to 54.07, 14.04 to 17.51 and 30.20 to 33.76 for vacuum-combined infrared dryer, respectively, and from 58.01 to 60.91, 12.58 to 13.84 and 33.57 to 33.96 for conventional dryer, respectively. While the L* values of the samples dried by vacuum-combined infrared dryer were lower than the those of samples dried by convectional dryer, the a* values were higher. The rapid energy transfer in infrared dryer may cause more pigment (melanoidins) formation compare to convectional drying. The b* values of samples dried in both dryers were similar. The infrared powers, drying temperatures and vacuum pressures had significant effect on the color values of pear slices ($p<0.05$). The difference between vacuum combined infrared and conventional dryers were found to be statistically significant only for L* results ($p<0.05$). Similar results were recorded for dried banana and lemon slices with vacuum-combined infrared dryer by Swasdisevi *et al*. (2007) and Salehi and Kashaninejad (2018), respectively.

RR, pH, titratable acidity and sugar components of fresh and dried samples were given in Table 1. The pH value and titratable acidity of fresh Deveci pear was 4.69 and 0.26%, respectively. It was determined that the pH and titratable acidity values of the dried samples varied between 4.71-4.87 and 0.08-0.14%, respectively. While the pH values of dried pears were slightly higher than fresh pear, titration acidity values were lower than fresh pear. It may be due to the decomposition of some acids (malic acid, ascorbic acid, citric acid etc.) during drying process. While the pH values of dried samples increased with decreasing the IP, acidity was decreased. The differences among IPs and vacuum pressures were found to be statistically significant only for pH values ($p<0.05$). Bozkır (2020) reported similar results for the pH values of dried orange slices in a vacuum-combined infrared dryer.

The RR of dried pear slices ranged from 3.66 to 4.19 g water/g d.m. The RR of pear slice dried with vacuum combined infrared dryer was slightly higher than those of pear slice dried with conventional dryer. The differ-

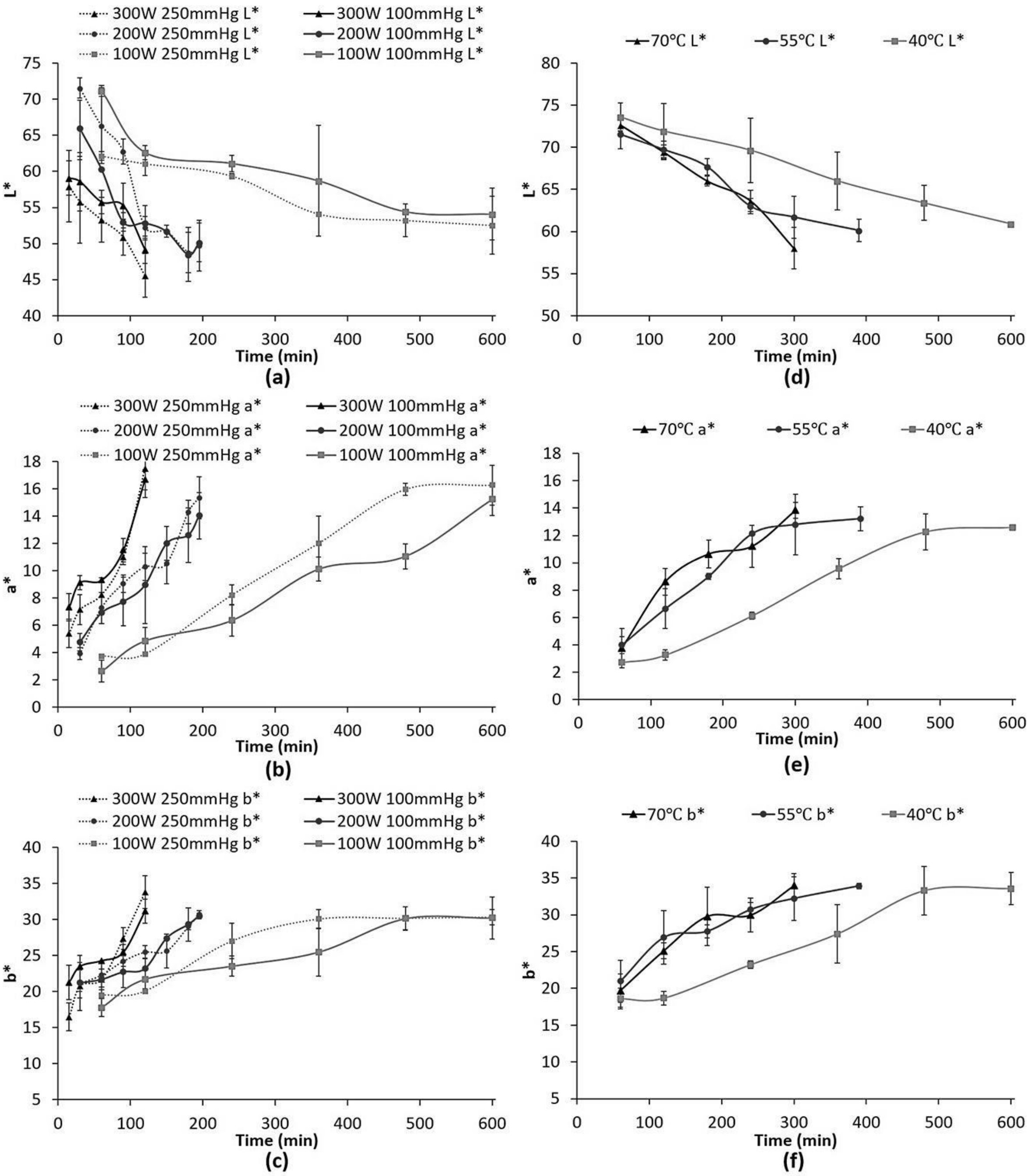

Fig. 2. L* (a), a* (b) and b* (c) values of pear slices dried under 100, 200 and 300 W IP at 250 mmHg and 100 mmHg vacuum pressure. L* (d), a* (e) and b* (f) values of pear slices conventionally dried at 40, 55 and 70 ºC, respectively.

Table 1. RR, pH, titratable acidity and sugar component results of vacuum-combined infrared and convectional drying

Sample		RR (gr water/g d.m)	pH	Acidity (% d.m)	Glucose (g/100g d.m)	Fructose (g/100g d.m)	Sucrose (g/100g d.m)	Total (g/100g d.m)
Fresh		-	4.69±0.61	0.26±0.03	20.20±3.48	30.62±4.25	2.34±0.40	53.16±6.92
300 W	250 mmHg	3.93±0.29^{bA}	4.71±0.06^{aA}	0.13±0.00^{aA}	23.12±1.99^{aA}	45.16±4.41^{aA}	0.85±0.01^{aA}	69.13±2.99^{aA}
	100 mmHg	4.01±0.10^{bA}	4.73±0.02^{aA}	0.12±0.00^{aA}	25.41±2.56^{aA}	42.85±5.03^{aA}	1.06±0.01^{aA}	69.32±4.67^{aA}
200 W	250 mmHg	4.10±0.08^{bA}	4.76±0.04^{abA}	0.10±0.00^{aA}	21.56±2.05^{aA}	49.16±6.02^{aA}	0.48±0.05^{aA}	71.20±8.15^{aA}
	100 mmHg	4.03±0.10^{bA}	4.77±0.07^{abA}	0.10±0.00^{aA}	23.51±3.09^{aA}	47.27±5.87^{aA}	1.32±0.02^{aA}	72.10±6.56^{aA}
100 W	250 mmHg	4.19±0.29^{aA}	4.85±0.00^{bA}	0.09±0.00^{aA}	21.06±2.17^{aA}	52.07±6.01^{aA}	0.45±0.04^{aA}	73.58±8.07^{aA}
	100 mmHg	4.06±0.34^{aA}	4.87±0.04^{bA}	0.08±0.00^{aA}	22.57±2.19^{aA}	48.97±5.38^{aA}	2.23±0.41^{aA}	73.77±3.88^{aA}
Convectional								
	70°C	3.66±0.16^{b}	4.71±0.02^{a}	0.14±0.02^{a}	25.34±3.66^{a}	42.65±5.29^{a}	3.97±0.26^{a}	71.96±6.55^{a}
	55°C	3.97±0.08^{b}	4.75±0.04^{ab}	0.13±0.00^{a}	25.93±3.34^{a}	47.05±4.28^{a}	4.18±0.69^{a}	77.16±6.02^{a}
	40°C	4.06±0.17^{a}	4.84±0.08^{b}	0.11±0.00^{a}	23.92±3.01^{a}	54.74±7.42^{a}	2.01±0.30^{a}	80.67±3.78^{a}

According to Duncan multiple comparison test, different lowercase letters show the difference between infrared powers in vacuumcombined infrared drying and the difference between temperatures in convectional drying, capital letters show the difference between vacuum pressures of Deveci pears dried with vacuum-combined infrared ($p<0.05$).

ence between vacuum-combined infrared dryer and conventional dryer was statistically significant ($p<0.05$). Zhao *et al*. (2019) were reported that big pores in the microstructure of samples dried by infrared dryer had a major positive influence on the rehydrate behavior of dried products. The RR of dried pear slices also decreased with increasing the IP for vacuum-combined infrared dryer and temperature for conventional dryer ($p<0.05$). After a while, the pore structure of the pear slices can be damaged by increasing infrared power and temperature. Therefore, the water absorption ability of the samples may decrease. Similar results regarding the change in RR of onions dried with infrared drier were reported by Mongpraneet *et al*. (2002). It was stated that the RR of onions dried decreases as the IP increases.

The amounts of glucose, fructose, sucrose and total sugar of fresh pear were found as 20.20, 30.62, 2.34 and 53.16 g/100 g d.m, respectively. The sugars contents of fresh pears were lower than those of dried pears. The similar results were reported for the total sugar and sucrose content of fresh and dried plum samples by Çevik and Bilişli (2002). In our study, the sugar contents of pears dried by infrared and convectional dryers were found to be close to each other ($p>0.05$). It was observed that generally, fructose, sucrose and the total sugar values decreased with increasing the IP for vacuum-combined infrared dryer and temperature for conventional dyer. However, for all sugar contents, the difference among IP, vacuum pressures and temperatures was found to be insignificant ($p>0.05$). Similar results were observed in banana slices dried at different temperatures by a convective dryer (Macedo *et al*., 2020).

HMF, total phenolic content and antioxidant activity of the pear slices were followed during the both drying processes, and the results were given in Table 2 and 3. HMF is an intermediate product of Maillard reaction and is major indicator of severity of heat treatment in food processing. HMF in samples dried at 100 W IP was not detected and sample dried at 200 W IP had very low HMF content at the 195th min. High amount of HMF was detected at 300 W at 120th minutes of drying. The highest decrease in L * and the highest increase in a * was also observed at the same conditions. It shows that non-enzymatic browning (Maillard reaction) at 300W IP occurred more rapid. However, a low amount of HMF was detected in samples dried by the conventional dryer only at 70 °C after 300 min. The color changes in samples dried by infrared dryer at low IP (100 and 200 W) and conventional dryer (40, 55 and 70 °C) may be due to the enzymatic browning reactions. HMF values of dried plum (2200 mg /kg), dates (100 mg /kg) and pineapple (280 mg /kg) were reported by Murkovic and Pichler (2006). The HMF values obtained in our study were much lower than the findings of Murkovic and Pichler (2006).

The TPC of dried samples by vacuum-combined infrared and conventional dryer ranged from 1909.79 to 2348.95 mg GAE/kg d.m and 2447.57 to 3795.55 mg GAE/kg d.m, respectively. TPC of dried pear slices was found higher than those of fresh pear. The pears dried by convectional dryer had higher TPC values than those of samples dried by vacuum-combined infrared drier. It can be thought that infrared light had a small effect on the transformation of bound phenolics into free form when compared to conventional heating. TPC values of pear slices dried by convectional dryer decreased with increasing drying temperature and time. It may be due to the rapid oxidation of these compounds with atmospheric O2. However, the TPCs of the samples dried by vacuum-combined infrared dryer were increased with rising IP and drying time. Drying at high IP may have led to free form conversion of bound phenolics. The TPC of the was found by Doymaz *et al.* (2016). The TPC of jujube samples dried at high vacuum pressure were also high. The high vacuum pressure provided better protection against oxidation. A similar change in TPC of jujube fruit was found by Doymaz *et al.* (2016). The TPC of jujube fruit dried at 62 and 125 W IP was 81.61 and 224.21 mg GAE/ 100 g (d.m.), respectively.

The ABTS and DPPH values of dried pear slices were ranged from 188.21 to 249.88 and 354.32 to 477.22 mmol Trolox eq/g d.m for vacuum-combined infrared dryer and from 315.65 to 392.85 and 405.09 to 513.26

mmol Trolox eq/g d.m for convectional dryer, respectively. DPPH and ABTS values of dried pear slices were found higher than fresh pear. The pears dried by convectional dryer had higher DPPH and ABTS values compare to samples dried by vacuum-combined infrared drier. TPC and antioxidant activity were also shown similar changes during the drying processes. According to the antioxidant activity results of garlic (Zhou *et al*., 2017) and pear (Liu *et al*., 2019) dried with infrared dryer, an increase in antioxidant activity was observed with increasing IP. While, for the HMF, DPPH and ABTS values, the differences among the IPs in infrared drying and temperatures in convectional drying were found to be statistically significant ($p<0.05$), for TPC values was insignificant ($p>0.05$). For the TPC, ABTS and DPPH values of pears dried by infrared and conventional dryer, the difference between drying times was found to be statistically significant ($p<0.05$).

Phenolic is the most important bioactive compounds. Phenolic compositions of fresh and dried pears were given in Table 4. Syringic, chlorogenic and ellagic acid contents of dried samples ranged from 3.95 to 4.27, 294.40 to 454.06 and 8.14 to 16.93 mg/kg d.m for vac-

Table 2. Changes in HMF, TFM, ABTS and DPPH content of Deveci pears during vacuum-combined infrared drying

Power (Watt)	Vacuum (mmHg)	Time (min)	HMF (mg/kg d.m)	TPC (mg GAE/kg d.m)	ABTS (mmol Trolox eq/g d.m)	DPPH (mmol Trolox eq/g d.m)
	Fresh	0	ND	622.56±55.79	70.69±9.34	264.10±24.67
300	250	30	ND	665±42.85^{aA1}	85.79±9.21^{aA1}	287.04±28.78^{bA1}
		60	ND	1748.97±79.50^{aA2}	118.75±10.0^{aA2}	300.87±25.48^{bA1}
		90	ND	1860.81±211.66^{aA3}	136.48±13.99^{aA2}	357.68±60.19^{bA12}
		120	132.94^{bB}	2348.95±250.56^{aA3}	249.88±24.14^{aA3}	477.22±70.80^{bA2}
	100	30	ND	646.19±56.47^{aA1}	85.55±10.76^{aA1}	258.30±38.71^{bA1}
		60	ND	947.39±190.84^{aA2}	87.89±8.44^{aA1}	298.25±37.86^{bA12}
		90	ND	1823.30±216.87^{aA3}	108.65±11.67^{aA2}	375.01±34.21^{bA2}
		120	46.62^{bA}	2187.05±200.99^{aA4}	244.07±26.70^{aA3}	408.46±33.88^{bA2}
200	250	30	ND	644.34±82.92^{aA1}	96.71±10.33^{bA1}	294.55±30.89^{aA1}
		60	ND	730.08±120.06^{aA1}	112.14±11.78^{bA12}	316.79±40.66^{aA1}
		90	ND	890.25±19.49^{aA1}	129.97±15.44^{bA12}	351.80±50.33^{aA2}
		195	26.62^{abB}	2058.09±123.98^{aA2}	206.72±33.17^{bA2}	391.20±75.28^{aA3}
	100	30	ND	715.95±148.87^{aA1}	92.66±8.44^{bA1}	288.28±29.87^{aA1}
		60	ND	726.59±63.69^{aA1}	123.29±13.87^{bA12}	309.47±25.79^{aA1}
		90	ND	961.22±83.65^{aA2}	155.76±10.44^{bA2}	327.37±56.38^{aA1}
		195	15.14^{abA}	2032.52±231.23^{aA3}	200.49±25.35^{bA3}	377.22±65.52^{aA1}
100	250	120	ND	865.81±49.61^{aA1}	109.51±10.55^{abA1}	294.70±53.53^{bA1}
		240	ND	1104.43±19.11^{aA1}	134.15±11.33^{ab2}	310.09±43.87^{bA12}
		360	ND	1574.17±231.51^{aA2}	163.45±15.42^{abA3}	315.54±52.08^{bA23}
		480	ND	1787.44±120.90^{aA2}	171.21±19.67^{abA34}	346.84±40.65^{bA23}
		600	ND	1931.68±110.67^{aA2}	192.23±59.24^{abA4}	361.02±52.53^{bA3}
	100	120	ND	812.95±57.56^{aA1}	106.22±9.90^{abA1}	272.28±14.71^{bA1}
		240	ND	1152.11±111.02^{aA1}	121.41±13.77^{abA1}	285.20±14.33^{bA1}
		360	ND	1305.53±420.27^{aA2}	124.36±29.78^{abA1}	308.91±12.32^{bA12}
		480	ND	1415.06±100.17^{aA3}	150.12±30.45^{abA2}	338.46±25.88^{bA3}
		600	ND	1909.79±107.55^{aA3}	188.21±25.16^{abA3}	354.32±35.79^{bA23}

According to Duncan multiple comparison test, lowercase letters show the difference between infrared powers in dried Deveci pear, capital letters show the difference between vacuum pressures, and numbers show the difference between drying times within

Table 3. Changes in HMF, TFM, ABTS and DPPH content of Deveci pears during convectional drying

Temperature (°C)	Time (min)	HMF (mg/kg d.m)	TFM (mg GAE/kg d.m)	ABTS (mmol Trolox eq/g d.m)	DPPH (mmol Trolox eq/g d.m)
Fresh	0	ND	622.56±55.79	70.69±9.34	264.10±24.67
70	60	ND	645.17±67.77^{aA}	74.87±14.77^{aA}	287.04±25.77^{bA}
	120	ND	1320.19±123.66^{aB}	129.15±12.8^{aA}	313.79±29.44^{bA}
	240	0.03^{A}	2281.61±175.21^{aC}	286.14±15.9^{aB}	325.30±24.55^{bA}
	300	1.80^{A}	2447.57±182.36^{aC}	315.65±20.56^{aC}	405.09±43.11^{bB}
55	60	ND	695.73±56.46^{aA}	79.36±13.52^{bA}	276.78±18.10^{aA}
	120	ND	1944.18±321.00^{aB}	84.50±12.34^{bAB}	282.53±20.12^{aAB}
	180	ND	2324.95±440.40^{aC}	137.32±23.21^{bBC}	363.19±40.66^{aB}
	240	ND	2605.46±307.24^{aC}	300.59±20.44^{bBC}	387.06±29.43^{aC}
	390	ND	2846.66±65.14^{aC}	356.72±11.76^{bC}	431.12±12.70^{aC}
40	60	ND	638.10±35.52^{aA}	80.32±15.17^{abA}	294.73±28.91^{bA}
	120	ND	785.30±67.31^{aA}	87.81±1.23^{abA}	319.36±30.49^{bAB}
	360	ND	2258.65±284.04^{aB}	252.80±38.30^{abB}	415.21±28.99^{bB}
	600	ND	3795.55±255.39^{aC}	392.85±21.02^{abC}	513.26±47.35^{bB}

According to Duncan multiple comparison test, lowercase letters indicate the difference between temperatures in Deveci pears dried with convectional dryer and capital letters indicate the difference between drying times in the same application ($p<0.05$).

Table 4. Phenolic composition of fresh and dried Deveci pears with vacuum-combined infrared and convectional dryer (mg/kg d.m.)

Sample		Catechin	Syringic	Epicatechin	Chlorogenic	Ellagic	Rutine
Fresh		27.83±3.25	3.48±0.59	251.73±26.77	210.21±10.21	-	16.89±3.07
300 W	250mmHg	ND	3.98 ± 0.46^{aA}	ND	314.68 ± 40.88^{aA}	8.14 ± 1.03^{bA}	1.23 ± 0.29^{aB}
	100 mmHg	ND	3.95 ± 0.49^{aA}	ND	294.40 ± 31.06^{aA}	11.35 ± 1.16^{bA}	ND
200 W	250mmHg	ND	4.53 ± 0.73^{aA}	ND	350.81±33.09aA	8.75 ± 1.01^{aA}	1.49 ± 0.16^{aB}
	100 mmHg	ND	4.08 ± 0.64^{aA}	ND	322.18 ± 35.77^{aA}	13.60 ± 0.62^{aA}	ND
100 W	250mmHg	ND	4.27 ± 0.70^{aA}	ND	454.06 ± 32.55^{bA}	9.65 ± 1.78^{aA}	0.71 ± 0.08^{aB}
	100 mmHg	ND	4.21 ± 0.22^{aA}	ND	404.06 ± 20.05^{bA}	16.93 ± 2.41^{aA}	0.59 ± 0.03^{aA}
Convectional							
70°C		ND	4.16 ± 0.40^{a}	ND	405.40 ± 40.56^{a}	13.88 ± 1.14^{b}	ND
55°C		ND	4.24 ± 0.12^{a}	ND	453.74 ± 20.29^{a}	13.91 ± 1.69^{a}	ND
40°C		ND	4.31 ± 0.27^{a}	ND	477.40 ± 33.77^{b}	14.03 ± 2.16^{a}	3.03 ± 0.60^{a}

According to Duncan multiple comparison test, different lowercase letters show the difference between infrared powers in vacuum-combined infrared drying and the difference between temperatures in convectional drying, capital letters show the difference between vacuum pressures of Deveci pears dried with vacuum-combined infrared ($p<0.05$).

Table 5. Sensory evaluation of dried Deveci pears with infrared and convectional dryer

Sample		Appearance	Color	Odor	Hardness degree	Hardness appreciation	Chewiness	Flavor	General taste
Vacuum-combined infrared drying									
100 W	250mmHg	6.71 ± 0.99^{aA}	6.53 ± 1.22^{aA}	6.08 ± 1.37^{aA}	5.63 ± 1.28^{aA}	5.53 ± 1.07^{abA}	6.20 ± 1.12^{aA}	6.41 ± 1.27^{aA}	6.26 ± 0.90^{aA}
	100mmHg	6.46 ± 0.62^{aA}	6.26 ± 0.91^{aA}	5.80 ± 1.18^{aA}	4.86 ± 1.04^{aA}	5.46 ± 1.16^{abA}	5.93 ± 1.19^{aA}	6.40 ± 1.04^{aA}	6.20 ± 0.86^{aA}
200W	250mmHg	6.14 ± 1.50^{aA}	6.00 ± 1.29^{aA}	5.69 ± 1.13^{aA}	4.53 ± 0.75^{aA}	5.20 ± 0.82^{bA}	5.80 ± 1.05^{aA}	6.50 ± 1.28^{aA}	6.23 ± 0.93^{aA}
	100mmHg	5.77 ± 1.31^{aA}	5.00 ± 1.38^{aA}	5.40 ± 1.24^{aA}	6.13 ± 0.66^{aA}	6.60 ± 0.94^{b}A	6.93 ± 1.22^{aA}	6.33 ± 1.03^{aA}	6.09 ± 0.85^{aA}
300W	250mmHg	7.14 ± 0.69^{aA}	6.80 ± 1.19^{aA}	6.78 ± 1.04^{aA}	4.80 ± 0.89^{aA}	6.06 ± 1.12^{aA}	7.07 ± 0.99^{aA}	7.77 ± 0.99^{aA}	7.42 ± 0.96^{aA}
	100mmHg	6.20 ± 0.97^{aA}	5.53 ± 1.29^{aA}	5.86 ± 1.21^{aA}	5.06 ± 1.15^{aA}	5.46 ± 1.20^{aA}	5.66 ± 1.03^{aA}	6.13 ± 1.15^{aA}	5.93 ± 1.12^{aA}
Convectional									
70°C		5.91 ± 0.99^{a}	5.66 ± 1.02^{a}	6.60 ± 1.18^{a}	4.00 ± 0.83^{a}	4.66 ± 0.88^{a}	4.93 ± 0.81^{a}	6.40 ± 1.26^{a}	5.60 ± 0.97^{a}
55°C		6.27 ± 0.93^{a}	6.13 ± 1.11^{a}	5.80 ± 1.13^{a}	5.60 ± 0.68^{a}	6.40 ± 0.68^{b}	6.00 ± 0.78^{a}	6.46 ± 0.99^{a}	6.46 ± 0.63^{a}
40°C		6.50 ± 1.19^{a}	6.73 ± 1.03^{a}	6.26 ± 1.48^{a}	5.53 ± 0.97^{a}	6.26±0.83a^{b}	6.66 ± 0.81^{a}	6.40 ± 1.23^{a}	7.40 ± 1.06^{a}

According to Duncan multiple comparison test, different lowercase letters show the difference between infrared powers in vacuum-combined infrared drying and the difference between temperatures in convectional drying, capital letters show the difference between vacuum pressures of Deveci pears dried with vacuum-combined infrared ($p<0.05$).

uum-combined infrared dryer, and from 4.16 to 4.31, 405.40 to 477.40 and 13.88 to 14.03 mg/kg d.m, for conventional dryer, respectively. While there were catechin and epicatechin in fresh pears, they could not be detected in dried samples. For catechin and epicatechin, similar results were detected in fresh and dried cocoa beans by Hurst *et al.* (2011). Rutine content of fresh pear was 19.89 mg/kg. Hovewer, a small amount of rutine was detected in dried pear samples. The disappearance of catechin and epicatechin and the decrease in the amount of rutine indicated that these compounds were decomposed during drying. Syringic acid and chlorogenic acid amounts in dried pears were found to be higher than fresh pear. As the IP in infrared drying and temperature in conventional drying increased, the syringic and chlorogenic acid contents of dried samples decreased. The decrease for chlorogenic acid was statistically significant ($p<0.05$). Especially chlorogenic acid content of dried sample under 250 mmHg vacuum pressure was higher than those of dried sample under 100 mmHg. While the ellagic acid was not detected in fresh pear, dried pears had ellagic acid content. Fukuda *et al.* (2004) noted that ellagitannins can be hydrolyzed to ellagic acids by heat treatment. This may indicate the presence of ellagitannins in the pear and ellagitannins in pear may be transformed into ellagic acid by the heat treatment during drying process. In this study, the amount of ellagic acid in dried pear increased with decreasing IP and drying temperature. For the chlorogenic and ellagic acid, the differences among the IPs in infrared drying and the temperatures in convectional drying was found to be statistically significant ($p<0.05$).

Mean scores of sensory attributes were given in Table 5. The sensory scores of the pear slices dried by the two different drying techniques were generally very close to each other. However, the samples dried at 300 w and 250 mmHg in vacuum-combined infrared dryer and at 40°C in convectional dryer usually had high scores. The samples dried at 300 w and 250 mmHg in vacuum-combined infrared dryer also had the highest scores on the appearance, color, odor, chewiness, flavor and general taste.

The pear slices dried at 250 mmHg vacuum pressure were usually given slightly higher sensory scores than slices dried at 100 mmHg. However, the differences between vacuum pressures for all sensory parameters were found to be statistically insignificant ($p>0.05$). Only the difference between IP was found to be statistically significant for the hardness appreciation scores ($p<0.05$).

V. CONCLUSIONS

Infrared radiation heating is widely used in several industries for drying process. In this study, the effects of two way infrared application under the vacuum pressure and convective hot air drying on physicochemical properties and bioactive compounds of dried pear were comparatively investigated. It was determined that the pear slices with the vacuum-combined infrared dryer could be dried in a shorter time compared to the conventional dryer. The vacuum-combined infrared dryer caused more brown pear color formation. The TPC and antioxidant activities of pear slices dried in the vacuum-combined infrared dryer were lower than those of the samples dried in a conventional dryer. For physicochemical properties, the differences between 100 and 250 mmHg vacuum pressures were usually negligible. The pear slices dried had better sensory scores. As a result, two-way infrared heating under vacuum pressure at 300W and 250 mmHg can be used successfully for production of high-quality dried pears. In addition, the oven equipped with a two-way infrared heating and vacuum pump system is more time and energy saving technique compared to a conventional dryer.

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