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The impact of pre-drying and different infrared powers on some quality parameters of apple chips fried by vacuum-combined infrared radiation

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SUMMARY: In this study, the use of vacuum-combined infrared radiation (VCIR) as a frying technique for the production of apple chips was investigated. The effects of a pre-drying treatment before frying on the quality parameters of apple chips were also evaluated. While the frying time of apple slices decreased by increasing the infrared power, the browning index value, 5-hydroxymethylfurfural (HMF) content, and oxidation ratio were raised. The frying times, oil contents, browning, and oxidation rates of apple chips were decreased with the pre-drying treatment. The sensory analyzes showed that the samples fried by vacuum-combined infrared radiation had the highest scores in all sensory characteristics than deep-fat fried samples. Pre-dried apple samples (41% moisture) fried at 350W infrared power under 400 mmHg vacuum pressure had the highest score for general acceptance. The results showed that VCIR would be an alternative frying method for producing healthier apple chips with less oil content and higher quality.

KEYWORDS: *Apple chips; Frying; HMF; Oxidation; Pre-drying; Vacuum combined infrared radiation.*

RESUMEN: ***Impacto del pre-secado y diferentes potencias de infrarrojo en algunos parámetros de calidad de chips de manzana fritos mediante radiación infrarroja combinada con vacío.*** En este estudio, se investigó el uso de radiación infrarroja combinada con vacío (VCIR) en la producción de chips de manzana como técnica de fritura. También se evaluaron los efectos del tratamiento de pre-secado antes de la fritura sobre los parámetros de calidad de chips de manzana. Si bien el tiempo de fritura de las rodajas de manzana disminuyó al aumentar la potencia infrarroja, el valor del índice de dorado, el contenido de 5-hidroximetilfurfural (HMF) y la oxidación aumentaron. Los tiempos de fritura, el contenido de aceite, el dorado y los parámetros de oxidación de los chips de manzana disminuyeron con el tratamiento de pre-secado. El análisis sensorial mostró que las muestras fritas con radiación infrarroja combinada con vacío tuvieron las puntuaciones más altas en todas las características sensoriales que las muestras fritas con mucha grasa. Las muestras de manzanas pre-secadas (41 % de humedad) fritas a una potencia infrarroja de 350W y una presión de vacío de 400 mmHg lograron la mayor aceptación de los panelistas. Los resultados mostraron que VCIR sería un método de fritura alternativo para producir chips de manzana más saludables, con menos contenido de aceite y alta calidad.

PALABRAS CLAVE: *Chips de manzana; Fritura; HMF; Oxidación; Presecado; Radiación infrarroja combinada al vacío.*

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1. INTRODUCTION

The apple has good flavor, color and texture and is also a nutritionally valued fruit, thus it has received worldwide popularity due to its unique properties (Shen *et al.,* 2018). Nowadays, there is an increasing consumer interest in apple chips based on their high nutritional content, ease of use and desirable sensory properties. Diets with high fruit and vegetable contents have been recommended, so there is an increasing demand for new, desirable and high-quality apple chips produced by innovative methods. This tendency increases the product availability and market diversification (Shen *et al.,* 2018). Apple chips as a healthy snack food are produced by different drying and frying methods.

Deep-fat frying is a popular way for the easy and fast preparation of delicious foods. The high temperatures (and high solid fat content) of the frying fat generally lead to the appreciated textural contradiction of the food: dry and crispy crust versus soft interior texture. Typical frying flavor is supplied by Maillard reactions in the crust. However, fried foods contain significant quantities of fats, attaining in some cases 1/3 of the total food product via weight. This ensures a high stage of satiety, but can also pose a risk to human health (Mellema, 2003). Vacuum frying is an acceptable choice for the production of high-quality dried fruits and vegetables in a shorter drying time than frequently used air-drying methods. Generally, drying under reduced pressure partially prevents deterioration regarding the browning and fading of the material, and the oxidation of frying oil which provides a final product with lower penetrated oil and higher shelf-life (Fan *et al.,* 2005).

Infrared technology is often used for the dehydration of vegetables, fish, pasta, and rice, fried meat, roasted cereals, roasted coffee and cocoa, and baked biscuits and bread (Rastogi, 2012). In infrared application, heat is transmitted by radiation. The temperature of the source determines the wavelength of infrared radiation. Higher temperatures produce shorter wavelengths and greater depth of penetration. Infrared heating provides efficient heat transfer, reducing operating time and energy cost. At the same time, the air in contact with the device is not heated. This allows the ambient temperature to be at a normal level (Rastogi, 2012). In recent years, the beneficial effects of infrared frying on the quality attributes of fried products have attracted much attention (Su *et al.,* 2022). A higher rate of heating and uniform heat distribution has been observed in chicken nuggets fried by far-infrared application (Udomkun *et al.,* 2019). Elizabeth *et al.* (2017) stated that lower acrylamide formation occurred in infrared-fried *Musa paradisiaca* than those of deep-fat fried.

Pre-drying (PD) reduces the initial moisture content in the product. A longer PD time results in less free moisture content to remove during frying (Gupta *et al.,* 2000). The partial drying of the apple samples before vacuum frying seems to reduce the oil content in the final product (Mariscal and Bouchon, 2008). Su *et al.* (2018) noted that pre-drying products using vacuum infrared technology resulted in products with lower oil content and higher quality. Furthermore, Cruz *et al.* (2018) reported that the PD process had a positive impact on color, texture, fat content, and acceptability of the product.

Traditional frying is an old process for manufacturing different food products worldwide. Recently, there has been special interest in the use of vacuum-combined frying applications. No studies are available regarding the effects of VCIR on the physical, chemical, and sensory properties of fried apple chips. In addition, over the years, several pre-treatments have been used to reduce PD time and improve fried product quality. However, the use of two-way infrared heating as a PD method to improve the quality properties of fried fruit and vegetable chips has not been explored. The main objective of this research was to investigate the use of VCIR to produce fried apple chips with lower oil content, and higher oxidative stability, physical, and sensory quality. Moreover, we observed the effects of PD treatments on the quality of apple chips by applying two-way infrared heating under vacuum pressure.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Sample preparation

Fresh apples (*Starking Delicious*) were purchased from the Hakkari province in Turkey. The moisture content in the fresh apple slices was 84.41±0.28% (w.b), as determined by the drying method (AOAC, 2003). Washed and peeled apples were cut into 3 mm thick slices. To prevent enzymatic browning, the apple slices were submerged for 5 min in a 0.75% citric acid solution. The surface of slices was wiped dry with absorbent paper approximately 10 seconds before frying. The sunflower oil (Yudum oils, Balıkesir, Türkiye) used for frying was purchased from the local market in Van, Turkey, and expressed as "fresh oil" in the tables.

2.1.2. Chemicals

A mixture of 37 FAME (C4-C24) was purchased from Supelco (Bellefonte, PA, USA). Acetonitrile (HPLC grade), n-hexane, acetic acid, ethanol, and methanol were purchased from Merck (Darmstadt, Germany). A HMF standard was obtained from Carl Roth (2295.2, Germany). Glucose, fructose, and sucrose were purchased from Sigma-Aldrich Co. (St. Louis, MO, USA).

2.2. Methods

2.2.1. Frying process

Vacuum-combined infrared (Uniterm, Ankara) radiation was used to fry the apple slices. The fryer system had two 250W infrared lamps placed on the ceiling inside the cabin. The distance between the oil surface and the lamps was kept at 12.5 cm. The slices were fried at 3 different infrared power settings (250, 300, and 350 W) and constant vacuum pressure (400 mmHg). For samples which were not subjected to pre-drying (NPD), the codes were NPD-250W, NPD-300W and NPD-350W, respectively. The deep-fat frying experiments were carried out in an atmospheric fryer (Philips Cucina, HD 6155, China) at 165 °C. In all frying experiments, the apple/oil ratio was kept at 1:20 (w/v). The frying process was terminated when the moisture content in the fried apple slices was reduced to 1.5-2.5% (w.b). After frying, a de-oiling step was applied to produce high quality fried apple chips with lower oil content and the apple chips were centrifuged at 1600 g for 5 min to remove excess oil. Five replicates of each treatment were made, and the frying oil was changed after each treatment.

2.2.2. Pre-drying and frying of apple slices

The infrared dryer had four 250W infrared lamps placed inside the oven on both the ceiling and the floor. The distance between the rack and the lamps was kept at 12 cm. Apple slices (80 g) were placed as a single layer on the rack. The PD of apple slices was carried out at 275W infrared power and 400 mmHg vacuum pressure. The PD process was terminated when the moisture content in the apple slices was reduced to 41.00% (w.b). The PD process took about 38 min. After PD, samples were fried at infrared radiation (250, 300, and 350W) under 400 mmHg vacuum pressure. For samples pre-dried by VCIR, the codes were PD-250W, PD-300W and PD-350W.

2.2.3. Moisture, pH, and acidity

The moisture contents, pH, and acidity values were determined by the methods proposed by AOAC (2003).

2.2.4. Sugars

Sugar content was analyzed by the modified method from Karaman *et al.* (2014). The de-oiled chips sample (1 g) was extracted with the addition of 15 mL of distilled water for 2 h using an orbital shaker (OS-3000, JEIO TECH, Korea) at room temperature. After the extraction, the sample was centrifuged at 3600 g for 10 min. The supernatant was filtered through a 0.45 µm membrane filter. Determination of the sugar composition of the filtrate was performed using the HPLC system (Shimadzu, Japan), equipped with a refractive index detector (RID-20A) and Intersil NH2 (4.6 x 250 mm ID, 5 µm) (GL Sciences Inc., Tokyo, Japonya) column. The column temperature was set at 25 °C. Chromatographic separation was obtained with acetonitrile:water (80:20, v/v) at a flow rate of 1.3 ml/min with an isocratic program. The sugars (fructose, glucose, and sucrose) appearing in the chromatograms were identified by comparing their retention time with the related standards. The results were expressed in a g/100 g dried sample. The concentration of total sugar was determined by adding up the concentrations of each detected sugar component.

2.2.5. Color analysis

The color properties of fried apple samples were measured using a Konica Minolta (CR-400, Japan) colorimeter. The color was determined in terms of the parameters L* (brightness), a* (redness-greenness), and b* (yellowness-blueness). Five slices and three readings per slice were recorded for the color measurement of the samples.

2.2.6. Browning index value

The browning index value was determined according to Akyıldız and Öcal (2006) with a slight modification. The de-oiled sample (1 g) and 25 mL distilled water were placed in beaker and homogenized at 10000 rpm for 30 s. The homogenate was kept at room temperature for one hour and then centrifuged at 800×*g* for 20 min. 15 mL of 95% ethanol were added to 10 mL of the supernatant. The mixture was again centrifuged at 800×*g* for 20 min. The degree of browning of the supernatant was determined by measuring the absorbance at 420 nm using the spectrophotometer (8453, Agilent, USA). The browning index was expressed in terms of absorbance (Abs/g initial DM).

2.2.7. HMF

For HMF extraction, de-oiled apple chips (1g) were put into a centrifuge tube in the presence of 15 mL methanol:water (80:20) and the mixture was shaken for 2 h in the dark at room temperature. The mixture was centrifuged at 8000×*g* at 10 °C for 10 min, and then the supernatant was transferred into an amber bottle. Extraction was performed again with 10 ml of the same solvent. The supernatants were combined and then the supernatant volume was made up to 25 ml with methanol:water (80:20) (Bakkalbaşı *et al.,* 2013). Methanolic extracts were prepared and stored at -24 °C until analysis. Chromatographic analysis was performed according to Colaric *et al.* (2005) with some modifications. The supernatants were filtered through a 0.45 µm PVDF syringe filter and immediately injected into the HPLC system (LC-20 AD-VP, Shimadzu, Kyoto, Japan). A symmetry C18 (250×4.6 mm id, particle size 5 µm) column was used for the separation of the HMF. The column temperature was 25 °C. A binary mobile phase consisting of 2% acetic acid in water (A) and 0.5% acetic acid in water:acetonitrile (1:1, v/v; B) was used. The gradient program was as follows: 10% B at 0 min and 20% B at 30 min at a flow rate of 1.0 mL/min. The HMF concentration was determined by the HMF standard.

2.2.8. Oil

The oil content in fried apple slices was determined using the Soxhlet extraction method (AOAC, 2003).

2.2.9. Oil extraction for fatty acid composition and oxidation parameters

The oil from fried apple slices was extracted by cold extraction. Fried apple slices were ground by a coffee grinder. Ground apple chips were mixed with n-hexane (10-fold of oil content in apple chips). The mixture was placed in the extraction flask under nitrogen and shaken at 180 rpm for 2 h in the dark at room temperature. After extraction, the mixture was filtered, and the solvent was removed by a rotary vacuum evaporator (R100, Buchi, Switzerland). The extracted oil was used to determine the peroxide value (PV) and p-anisidine value (AV) (Bakkalbaşı *et al*., 2013). The PVs and AVs of the samples were determined by official methods recommended by AOCS (Cd 8-53 and Cd 18-90, respectively) (AOCS, 2006). The TOTOX value was calculated by the following equation (Haq *et al.,* 2017): TOTOX value=2(PV) + AV

2.2.10. Fatty acid composition

The fatty acid composition of the oil extracted from samples was determined by an Agilent 6890N (Agilent Technologies, Little Falls, DE, USA) GC donated with a flame ionization detector, using a HP-88 column (0.25 mm id × 100 m; Agilent J&W, Santa Clara, CA, USA,) after converting the lipid fractions to fatty acid methyl esters (IUPAC, 1991). Peaks were identified by comparing their retention times to standard fatty acid methyl esters (Supelco, Bellefonte, PA, USA).

2.2.11. Sensory evaluation

A sensory evaluation of the apple chips was conducted by 16 semi-trained panelists. The samples were coded with a 3-digit random number and served to selected panelists using a completely randomized design. The appearance, color, odor, crispness, chewiness, taste, oiliness, and general acceptance of fried apple chips were evaluated. Each characteristic was rated using a nine-point hedonic scale (1= extremely dislike and 9= extremely liked) (Soysal *et al.,* 2009). The fried samples were kept at room temperature for one day and then sensory evaluation was performed.

2.3. Statistical analysis

The experimental values were represented in their averages along with the standard deviation. The data obtained were analyzed using SPSS 20.0 software for one-way variance analyses. Duncan's multiple comparison test was applied to identify significantly different groups ($p < 0.05$).

3. RESULTS AND DISCUSSION

3.1. Frying time, moisture content and some chemical parameters of apple chips

Before frying, there are a series of treatments applied to food materials to produce products with better quality and more nutritional value in a shorter processing time. Conventional pretreatments such as blanching, freezing, osmotic dehydration, coating, and PD are applied to foods before frying process to prevent enzymatic activity, to reduce the initial moisture content, and to modify their morphology (Su *et al.,* 2021). The frying times, moisture contents, pH, and titratable acidity values of the fresh and fried samples are given in Table 1. Depending on the infrared power, the frying time of the samples ranged from 45 to 5 minutes 50 seconds. The moisture contents in the fried samples varied between 1.72-2.37%. The results showed that infrared power significantly affected the moisture contents in the NPD samples ($p < 0.05$). The frying time of the samples decreased by increasing the infrared power (250-350 W). The lowest frying time (5 min 50 sec) was observed in the pre-dried sample at 350W. The frying time of the samples fried under atmospheric pressure (6 min) was low due to the high temperature (165 °C). The PD treatment also reduced the frying time when compared to the NPD treatment. It may be due to the low free moisture content in the samples after PD. The combination of these technologies showed a positive effect on frying time.

The pH and titratable acidity values for the fried samples varied between 4.16-4.42 and 0.88-1.68%, respectively. The pH values and acidity of NPD apple chips and deep-fried apple chips were similar to those of the fresh sample. However, the pH values and acidity of pre-dried apple chips were different from fresh apple, deep-fat fried chips, and NPD apple chips ($p < 0.05$). While the pH values for the fried sample increased with increasing the infrared power, their acidity decreased. For pH and acidity, the differences between PD and NPD samples at the same infrared power settings were significant ($p < 0.05$). For pH only, the difference between infrared power settings in PD and NPD samples was significant ($p < 0.05$). Although citric acid was applied to all frying samples as a pre-treatment, the highest acidity values were found in the PD samples. The short frying time for the PD samples may have prevented citric acid degradation at high temperatures.

The fructose, glucose, sucrose, and total sugar contents in the fried apple chips are given in Table 1. The

Table 1. Frying times, moisture, pH and acidity of fried apple chips (n=5)

Sample	Frying times (min)	Moisture Content (wb %)	pH	Acidity (% DM)	Sugar (g/100g DM)			
					Fructose	Glucose	Sucrose	Total
Fresh apple		84.41±0.28*	4.35±0.02	1.09±0.09	43.63±1.12*	24.02±1.73*	14.71±1.23*	82.36±1.63*
NPD-250W	45	2.23±0.12^{bB}	4.32±0.03^{cA}	1.16±0.16^{aA}	27.19±3.87^{bcA}	16.91±0.82^{abA}	4.02±0.19^{aA}	48.13±4.51^{bcA}
NPD-300W	19	2.35±0.19^{bB}	4.37±0.01^{cdB}	1.00±0.21^{aA}	24.45±1.50^{bA}	16.24±0.12^{abA}	3.91±0.33^{aA}	44.61±1.71^{bA}
NPD-350W	11	1.72±0.09^{aA}	4.41±0.04^{deC}	0.95±0.16^{aA}	23.64±1.06^{bA}	16.20±0.87^{abA}	3.49±1.16^{aA}	43.34±0.96^{abA}
PD-250W	33	2.37±0.02^{bA}	4.16±0.02^{aA}	1.68±0.29^{bA}	29.78±0.86^{cA}	18.88±0.26^{bA}	4.52±1.42^{aA}	53.19±0.82^{cA}
PD-300W	14	2.17±0.14^{bA}	4.21±0.02^{abAB}	1.65±0.01^{bA}	29.66±0.18^{cA}	16.60±1.35^{abA}	4.36±1.57^{aA}	50.63±3.11^{bcA}
PD-350W	5 min 50 sec	2.34±0.14^{bA}	4.22±0.00^{bB}	1.47±0.09^{bA}	28.43±0.85^{bcA}	16.41±1.34^{abA}	4.31±0.71^{aA}	49.16±0.22^{bcA}
Deep-fat frying	6	2.32±0.04^{b}	4.42±0.04^{e}	0.88±0.11^{a}	18.86±2.65^{a}	14.52±1.91^{a}	2.87±1.61^{a}	36.26±6.19^{a}

Data were expressed as mean ± standard deviation. Different lowercase letters indicate the significant differences among all values within the same column. Different capital letters indicate the significant differences among infrared power settings within the same initial moisture (Duncan test, $p < 0.05$). NPD: Not subjected to pre-drying, PD: Pre-drying. * The data on fresh apple was reported in a previous study (Uğurlu *et al.*, 2023) sugar contents in the apple slices decreased after the frying process compared to fresh apple. The total sugar contents in the fried apple chips varied between 36.26 and 51.89 g/100 g DM. The fructose, glucose, and total sugar contents in the apple chips fried with a VCIR fryer were higher than those fried in a deep-fat fryer ($p < 0.05$). The increasing infrared power in VCIR frying resulted in a decrease in fructose, glucose, sucrose, and total sugar contents. A similar trend was observed for the fructose and glucose contents in vacuum-fried papaya chips (Soto *et al.,* 2021). However, in our study, with increasing infrared power, the changes in sugar contents were insignificant. The sugar contents of PD apple chips were higher than those of NPD apple chips samples. The results revealed that PD had a significant effect on the protection of sugar content. The differences between the NPD and PD samples were significant in terms of fructose in samples treated at 300W, and for fructose and total sugar contents in the samples treated at 350W infrared power ($p < 0.05$). The decrease in sugar content may be related to their participation in non-enzymatic browning reactions.

3.2. Color, browning index, and HMF content of fried apple chips

The color values (L*, a*, and b*) of fried samples are shown in Table 2. The L* value is a critical parameter in the frying industry, and is generally used as a quality control factor (Mariscal and Bouchon, 2008). After the frying process, there was a decrease in the lightness (L*) of all the samples when compared to fresh apple. The deep-fat fried samples had the lowest L* value (51.19). The L* values for apple chips fried with VCIR were higher than those for deep-fat fried apple chips. The results were in agreement with data reported by other researchers (Mariscal and Bouchon, 2008; Su *et al.,* 2022). The L* values decreased as the frying power increased from 250 to 350W. Similar observation was reported by Su *et al.* (2022) for infrared fried apple slices. Low L* values for fried samples indicate a dark color and are mainly associated with non-enzymatic browning reactions (Dueik *et al.,* 2010). The changes in the L* values for the NPD samples with increasing infrared power were higher than those for PD samples. However, the PD process and infrared power did not significantly affect the L* values ($p > 0.05$).

The redness (a*) and yellowness (b*) values for the apple slices increased after the frying process. The a* value for the deep-fat fried sample was significantly higher than those for the PD and NPD samples, (except NPD-350W) ($p < 0.05$). The b* value for the deep-fat fried sample was only significantly lower than that for the NPD-350W sample ($p < 0.05$). The a* and b* values for samples fried by VCIR increased with increasing infrared power. However, the effect of infrared power on the a* values of the NPD samples was significant ($p < 0.05$). Long-term infrared radiation was applied to the NPD sample. Depending on the infrared power and exposure time, more non-enzymatic browning reactions may have developed on the surface of the NPD samples. In addition, the PD process did not significantly affect the a* and b* values ($p > 0.05$). Su *et al.* (2018) reported that the PD has a negative effect on the color of chips, by increasing their redness. Our results (L*, a*, and b* values) showed that the PD had a negligible effect on the color of fried apple chips.

The darkening that occurred during the frying process would be a result of non-enzymatic browning, which is expressed by the browning index value (Su *et al.,* 2018). In this study, the browning index values for fried samples changed between 0.063 and 0.373 Abs/g initial DM ($p < 0.05$) (Table 2). A higher browning index value was observed in deep-fat fried apple chips compared to those fried by VCIR. It may be due to the higher frying temperature in atmospheric deep-fat frying. Dueik and Bouchon (2011) reported similar results. An increasing infrared power in the VCIR fryer increased the browning index value for NPD and PD samples The infrared power significantly affected the browning index values for the NPD samples ($p < 0.05$). NPD samples had a higher browning index values when compared to PD samples. Longer frying time could be responsible for the darkening color development in the NPD sample. The differences between the browning index values for NPD and PD samples prepared at 300 and 350W infrared powers were significant ($p < 0.05$). The changes in the HMF contents of the apple chip samples are given in Table 2. The HMF contents in the fried samples ranged between 167.99 and 1294.01 mg/kg DM ($p < 0.05$). The HMF contents in the NPD and PD samples increased with increasing infrared power. However, the infrared power

Table 2. L*, a*, b*, browning index value, and HMF contents in apple chips (n=5)

Sample	L*	a*	b*	Browning index (Abs/g initial DM)	HMF (mg/kg DM)
Fresh apple*	74.37±0.82	0.39±0.56	18.00±1.55	0.001±0.00	-
NPD-250W	64.61±2.68[cA]	5.74±1.30[aA]	29.61±1.09[abcA]	0.082±0.01[abA]	232.16±17.53[aA]
NPD-300W	63.27±3.38[bcA]	6.81±2.04[aA]	29.92±1.91[bcA]	0.094±0.00[bcA]	299.77±72.26[aA]
NPD-350W	61.55±2.03[bcA]	9.54±2.90[bcB]	31.12±1.18[cA]	0.112±0.00[cB]	479.28±71.04[bB]
PD-250W	61.61±2.00[bcA]	6.66±1.22[aA]	27.41±2.30[aA]	0.063±0.00[aA]	167.99±35.07[aA]
PD-300W	61.26±2.89[bcA]	6.96±3.34[aA]	28.51±1.77[abA]	0.065±0.00[aA]	172.47±32.13[aA]
PD-350W	60.51±3.71[bA]	7.59±1.89[abA]	29.72±2.87[abcA]	0.070±0.00[aA]	208.31±21.62[aA]
Deep-fat frying	51.19±4.28[a]	11.39±1.99[c]	28.45±0.93[ab]	0.373±0.02[d]	1294.01±98.47[c]

Data were expressed as mean ± standard deviation. Different lowercase letters indicate the significant differences among all values within the same column. Different capital letters indicate the significant differences among infrared power settings within the same initial moisture (Duncan test, $p < 0.05$). NPD: Not subjected to pre-drying, PD: Pre-drying. * The data on fresh apple was reported in a previous study (Uğurlu *et al*., 2023)

significantly affected the HMF contents in the NPD samples ($p < 0.05$). Moisture content and especially the used frying method significantly affected ($p < 0.05$) the HMF formation, and the HMF contents of the NPD samples were higher than those of the PD samples. Pre-drying application followed by infrared frying could help to reduce the HMF content in apple chips. This can be explained by the lower frying time and lower initial water contents in the apple slices. The deep-fat fried samples showed the highest HMF contents. The higher contents in HMF in the deep-fat fried samples indicated that the infrared frying was an important contributor to the preservation of the quality parameters of the samples due to their lower HMF contents.

3.3. Oil content, fatty acid composition and oxidation parameters

Oil content is an important parameter to evaluate the quality of fried products. High oil retention in a fried product can affect the flavor of the product, however, fried products with high oil content are commonly considered unhealthy (Shen *et al.,* 2018). The oil contents in the apple chips ranged between 30.69 and 39.69 g oil/100 g ($p < 0.05$) (Table 3). The increasing infrared power in VCIR decreased the oil content in the fried sample ($p < 0.05$). In addition, samples with lower initial moisture contents (41%) showed lower oil contents than their counterparts with higher initial moisture contents (84%). This indicates that the PD pre-treatment led to a significant decrease in oil content ($p < 0.05$). High frying temperature and PD treatment produce a firm crust around the food. This crust functions as a physical barrier, impeding oil penetration into the inner part of the product. This results in a reduction in oil uptake (Movahhed and Chenarbon, 2018). Pandey *et al.* (2020) reported that partial drying before vacuum frying reduces the oil uptake in papaya chips. The oil content seems to be related to the moisture content. While the highest oil absorption was observed in samples fried under atmospheric conditions, the pre-dried vacuum fried samples showed the lowest oil absorption. Since oil can only penetrate where water has evaporated, oil penetration only occurs where the temperature has been sufficiently high, namely in the crust (Mellema, 2003). The high reduction in oil uptake of pre-dried apple slices is mainly due to crust development and surface changes occurring during the drying step. In fact, crust microstructure development (mean pore size, connectedness and permeability) has a marked effect on oil absorption (Mariscal and Bouchon, 2008). Therefore, the PD process led to a reduction in fat content, which would be useful for the food industry for producing fried foods with lower fat contents. In our study, while high frying temperature (350W) decreased the oil contents in the fried samples, deep-fat fried ap-

Table 3: Oil content and fatty acid composition of fried apple chips (n=5)

Sample	Oil content (g oil/ 100 g)	Fatty acids					
		Palmitic C16:0	Stearic C18:0	Oleic C18:1	Linoleic C18:2	Linolenic C18:3	Arachidic C20:0
Fresh oil	-	7.40±0.52^{aA}	3.68±0.29^{aA}	32.40±0.04^{aA}	55.84±0.72^{aA}	0.29±0.06^{aA}	0.24±0.00^{aA}
NPD-250W	38.10±0.07^{eC}	7.58±0.38^{aA}	3.53±0.05^{aA}	32.03±0.23^{aA}	56.23±1.20^{aA}	0.20±0.04^{aA}	0.23±0.03^{aA}
NPD-300W	35.92±0.02^{dB}	7.81±0.60^{aA}	3.51±0.01^{aA}	33.15±1.11^{aA}	55.01±0.96^{aA}	0.17±0.05^{aA}	0.19±0.04^{aA}
NPD-350W	35.13±0.18^{cA}	8.21±1.01^{aA}	3.15±0.35^{aA}	32.66±0.56^{aA}	55.25±1.07^{aA}	0.29±0.05^{aA}	0.31±0.07^{aA}
PD-250W	34.72±0.31^{cC}	6.86±0.14^{aA}	3.85±0.37^{aA}	33.02±0.72^{aA}	55.64±1.15^{aA}	0.25±0.03^{aA}	0.26±0.04^{aA}
PD-300W	32.65±0.35^{bB}	7.22±0.39^{aA}	3.40±0.09^{aA}	32.77±0.48^{aA}	56.05±2.15^{aA}	0.22±0.02^{aA}	0.17±0.06^{aA}
PD-350W	30.69±0.28^{aA}	8.09±0.89^{aA}	3.35±0.20^{aA}	32.46±0.29^{aA}	55.35±1.65^{aA}	0.27±0.05^{aA}	0.29±0.04^{aA}
Deep-fat frying	39.69±0.42^{f}	7.08±0.38^{aA}	3.70±0.22^{aA}	32.82±1.28^{aA}	55.63±1.32^{aA}	0.29±0.01^{aA}	0.31±0.08^{aA}

Data were expressed as mean ± standard deviation. Different lowercase letters indicate the significant differences among values within the same column. Different capital letters indicate the significant differences among infrared power settings within the same initial moisture (Duncan test, $p < 0.05$). NPD: Non pre-drying, PD: Pre-drying.

ple chips (165 °C) had higher oil contents (39.69 g oil/100 g) than those fried at low infrared power (at low temperature) by VCIR.

C18:2 was the most abundant fatty acid found in fresh sunflower oil (55.84%) followed by C18:1 (32.40%), C16:0 (7.40%), C18:0 (3.68%), C18:3 (0.29%) and C20:0 (0.24%) (Table 3). The C18:1 and C18:2 contents in fried samples varied between 32.03-33.15 and 55.01-56.23%, respectively. For fatty acids, the difference between samples was not significant ($p > 0.05$). In NPD (84% moisture) and PD (41% moisture) samples, the infrared power did not significantly affect the fatty acid contents in samples ($p > 0.05$).

Hydroperoxides are the primary products of lipid oxidation; therefore, the determination of PV can be used as an oxidation index for the early stages of lipid oxidation (Basuny *et al.,* 2012). The anisidine analysis is used to assess the secondary oxidation products of oil mostly aldehydes such as 2,4-dienals and 2-alkenals, which are produced by the decomposition of hydroperoxides (Alizadeh *et al.,* 2016). A combined determination of primary oxidation products through PV and the secondary oxidation compounds via measurement of AV is commonly expressed as TOTOX (Koohikamali and Alam, 2019). The oxidation parameters of oils from fried apple chips and fresh sunflower oil are given in Table 4. The p-anisidine, peroxide and TOTOX values

Table 4. The oxidation parameters of samples (n=5)

Sample	PV (meq O_2/ kg oil)	AV	TOTOX value
Fresh oil	5.62±0.47	4.44±0.06	15.69±0.71
NPD-250W	18.94±0.11^{bcA}	12.84±1.49^{abA}	50.73±1.67^{bA}
NPD-300W	24.01±1.49^{cdA}	18.41±0.38^{bcB}	66.43±2.61^{cAB}
NPD-350W	25.52±6.47^{dA}	23.21±0.65^{cC}	74.26±12.91^{cB}
PD-250W	8.64±1.27^{aA}	6.79±0.51^{aA}	24.08±2.02^{aA}
PD-300W	14.95±0.68^{bB}	8.90±0.13^{aB}	38.80±1.23^{bB}
PD-350W	16.35±1.82^{bB}	9.29±0.10^{aB}	41.99±3.76^{bB}
Deep-fat frying	26.15±0.00^{d}	52.87±6.11^{d}	105.17±6.11^{d}

Data were expressed as mean ± standard deviation. Different lowercase letters indicate the significant differences among all values within the same column. Different capital letters indicate the significant differences among infrared power settings within the same initial moisture (Duncan test, $p < 0.05$). NPD: Not subjected to pre-drying, PD: Pre-drying.

of fresh oil were found as 4.44±0.06, 5.62±0.47 meq O_2/kg oil, and 15.69, respectively. The *p*-anisidine, peroxide and TOTOX value of fresh oil were lower than those extracted from the fried sample. AV, peroxide, and TOTOX values of the samples significantly increased by increasing the infrared power in both pre-dried and NPD samples ($p < 0.05$), except for the PVs of the NPD samples ($p > 0.05$). The pre-drying process affected the oxidation result. The higher *p*-anisidine, peroxide, and TOTOX values were observed for NPD samples when compared to those of pre-dried samples ($p < 0.05$). All apple chips fried with VCIR exhibited significantly lower *p*-anisidine, peroxide, and TOTOX values than the deep-fat fried samples ($p < 0.05$). These results confirmed that the infrared pre-treatment can significantly reduce the p-anisidine, peroxide, and TOTOX values for the samples under certain conditions. Basuny *et al*. (2012) noted that the formation and decomposition of hydroperoxides in oil from vacuum fried samples were less than those of deep-fat fried due to the lower temperature applied and lower oxygen content. In our study, the frying process of pre-dried apple slices at 250W infrared power and 400 mmHg vacuum pressure showed the lowest peroxide, p-anisidine, and TOTOX values. It can be affirmed that the synergism between PD and VCIR increases the stability of frying oil.

3.4. Sensory evaluation

Apple chips were assessed for sensory acceptability in terms of appearance, color, odor, crispiness, chewiness, taste, oiliness and general acceptance. The results of the sensory evaluation of fried apple chips are given in Table 5. Apple chips produced by the deep-fat frying process gave lower sensory scores than VCIR-applied samples. Particularly, deep-fat frying resulted in an undesirable appearance and dark color in apple chips. While the scores for all sensory parameters regarding the PD samples were raised with increasing infrared power, irregular changes in the NPD sample were observed with increasing infrared power. In the PD samples, the infrared power significantly affected their appearance, color, odor, crispiness, chewiness, taste, and general acceptance ($p < 0.05$). The infrared power significantly affected the appearance of NPD samples ($p < 0.05$). High infrared power improved the chewability of sample. This may be due to the PD pre-treatment and reduction in oil content during frying at high infrared power. Hedonic scores for the crispness, chewiness, oiliness, taste, and general acceptance generally increased with decreasing oil content in the PD samples. PD-350 sample with the lowest oil content had the highest scores for all sensory parameters. Interestingly, the PD-350 sample had a higher darker color than the other PD samples. However, it showed less darker color than all NPD samples. The panelists gave the highest appearance and color scores for the PD-350 sample. In Turkey, consumers are generally familiar and mostly prefer sun-dried fruits which are darker than artificially-dried fruits. Therefore, it was concluded that panelists gave higher scores to apple chips which had a preferable degree of browning based on their traditional choices.

4. CONCLUSIONS

In this study, the production of apple chips with VCIR was investigated. In addition, the effect of the PD treatment on the quality parameters of apple chips was determined. The apple chips fried by

Table 5. Sensory characteristics of fried apple chips (n=5)

Sample	Appearance	Color	Odor	Crispiness	Chewiness	Taste	Oiliness	General Acceptance
NPD-250W	5.16±1.58^{bA}	5.66±1.37^{bA}	7.08±1.31^{bA}	7.33±1.37^{cA}	7.00±1.41^{bA}	6.91±1.44^{bcA}	6.25±1.81^{bcA}	6.50±1.38^{bA}
NPD-300W	8.00±1.20^{cB}	7.08±2.31^{cA}	6.50±1.62^{abA}	6.91±1.56^{bcA}	7.00±1.47^{bA}	6.00±2.04^{abcA}	4.75±2.22^{abA}	6.25±1.81^{bA}
NPD-350W	5.66±1.82^{bA}	5.83±1.99^{bA}	6.66±1.61^{bA}	7.33±1.37^{cA}	7.25±1.28^{bA}	5.41±2.10^{abA}	5.58±2.39^{abcA}	6.33±1.82^{bA}
PD-250W	7.16±1.11^{cA}	7.16±0.93^{cA}	6.25±1.35^{abA}	4.58±1.62^{aA}	5.25±1.35^{aA}	5.83±1.40^{abcA}	6.25±1.48^{bcA}	5.91±1.16^{bA}
PD-300W	7.41±0.79^{cAB}	7.83±0.71^{cAB}	7.41±0.99^{bB}	5.83±1.80^{abA}	5.25±1.71^{aA}	6.50±1.08^{bcAB}	6.50±1.67^{bcA}	6.41±0.79^{bA}
PD-350W	8.08±0.51^{cB}	8.25±0.75^{cB}	7.41±0.90^{bB}	7.50±1.00^{cB}	7.66±0.98^{bB}	7.33±1.37^{cB}	6.75±1.71^{cA}	7.66±0.77^{cB}
Deep-fat frying	3.08±1.37^{a}	2.50±1.31^{a}	5.25±2.22^{a}	4.75±2.17^{a}	5.41±2.27^{a}	4.66±1.92^{a}	4.25±2.56^{a}	4.33±1.77^{a}

Data were expressed as mean ± standard deviation. Different lowercase letters indicate the significant differences among all values within the same column. Different capital letters indicate the significant differences among infrared power settings within the same initial moisture (Duncan test, $p < 0.05$). NPD: Not subjected to pre-drying, PD: Pre-drying.

VCIR had higher lightness (L*) and lower of browning rate, HMF content, oil content, and oxidation rate than deep-fat fried samples. While the frying times and oil contents in the samples decreased with increasing infrared power, the browning rate, HMF content, and oxidation rate increased. The PD treatment reduced the oil absorption, allowing to obtain products with lower fat content. In addition, the PD samples had lower browning values and oxidation rates than the NPD samples. Panelists in the sensory evaluation overwhelmingly preferred the apple chips fried by VCIR. The PD apple chips fried by VCIR had the highest scores for all sensory characteristics. As a result, VCIR was shown to be a promising technique for the frying process that can be used to reduce the oil content and oxidation rate in fried apple slices while preserving the color of the product. In particular, applying this technique with PD treatment gave better results for the quality characteristics of apple chips.

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