INVESTIGATION OF INFRARED AND HOT AIR OVEN FOR DRYING FRESH APPLE SLICES AT DIFFERENT TEMPERATURES

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Abstract
This study examined infrared and hot air oven drying methods for fresh apple slices under different drying temperatures from 40 °C to 80 °C with 10 °C intervals for approximately 10 hrs drying time. The drying curves of the sample weight and moisture content versus drying time were presented. The main calculated parameters were the total colour change, chroma, colour index, whiteness index, browning index, hue angle, rehydration capacity, shrinkage (%), bulk density (g/mL), area (mm^2) and volume (mL). The correlation analysis showed that for both drying methods all the calculated parameters did not significantly ($P > 0.05$) correlate with the drying temperatures except total colour change, colour index and whiteness index which significantly ($P < 0.05$) correlated linearly with the drying temperatures. The significant correlation values were between -0.887 and 0.980. It was observed that the infrared drying showed a higher total colour change than the hot air oven drying. Future studies will consider in detail the combined drying methods, mathematical modelling of the drying curves and optimization of the operating parameters for different varieties of fresh apples and other fresh products to ensure better control of the drying operations and quality improvement of the final product for consumption and storage.

Key words: *apple slices; drying behaviour; shrinkage, rehydration capacity, colour analysis.*

INTRODUCTION

Drying has been one of the commonly used methods to preserve foods such as fruits and vegetables for human consumption (*Aral & Bese, 2016*). It is done to remove moisture through evaporating and sublimation processes including heat and mass transfer mechanisms (*Jafari, Movagharnejad & Sadeghi 2020*). Fruits and vegetables are dried to inhibit microbial, enzymatic and quality decay (*Aral & Bese, 2016*). Several authors namely but not limited to the following have studied the drying characteristics of fruits and vegetables using different drying methods (*Aidani, 2016; Karaaslan, Ekinci & Akbolat, 2017; Bozkir et al., 2019; Jafari, Movagharnejad & Sadeghi 2020*). For instance, *Aidani, (2016)* studied hayward kiwifruits by combined infrared-vacuum whereas *Jafari, Movagharnejad & Sadeghi (2020)* examined the effect of thickness of samples, air velocity and infrared power on the drying kinetics and quality attributes of blanched slices during infrared drying. Particularly, apples are cultivated in many countries of the world and can be eaten in various forms as fresh, dried, juice, jam or marmalade (*EL-Mesery, Kamel & Emara, 2021*). They provide vast health and nutritional benefits to humans like anti-inflammatory effects and chronic disease prevention (*Khudyakov, Sosnin, Shorstkii & Okpala, 2022*). In the literature, considerable studies have been performed and more are being conducted to determine the optimum drying methods, processing factors, energy consumption, physical and chemical quality characteristics of dried apple slices for their storage and reuse (*EL-Mesery, Kamel & Emara, 2021; Joardder & Karim, 2022; Khudyakov, Sosnin, Shorstkii & Okpala, 2022*). Most importantly, consumers prefer dried products according to their physical qualities such as colour, shape, aroma and appearance (*Cetin, Saglam and Demir, 2019*). The present study aimed at evaluating the colour attributes, moisture content (g/g dry basis), rehydration capacity, shrinkage (%), bulk density (g/mL), area and volume of dried apple slices under infrared and hot air oven drying methods under different drying temperatures.

MATERIALS AND METHODS

Sample and drying methods

Fresh whole red delicious apples (Fig. 1 a) were purchased from a supermarket in Prague, Czech Republic. The samples were kept in a refrigerator at 5 °C. Before the experiments, the samples were removed and allowed to cool to a laboratory temperature of 24.26±0.50 °C and humidity of 41.6±2.42%. A slicer was used to cut the fresh apples into a cylindrical size of 10 mm. The dimensions (diameter and thickness) of the fresh and dried apple sliced samples were accurately measured using a digital calliper with an accuracy of 0.01 mm. The mass of the fresh and dried apple sliced samples was measured using a digital balance with an accuracy of 0.01. Infrared and hot air oven methods were used to dry the freshly sliced apple samples (Fig. 1 b, c and d) at different drying temperatures from 40 °C to 80 °C with 10 °C intervals.

Colour analysis

The colour values of the fresh and dried apple slices at the different drying temperatures were measured using the RGB colour analyzer (RGB-2000 Voltcraft). The RGB (Red, Green and Blue) values were converted to Lab values using an online converter. The total colour change (ΔE), chroma (ΔC), colour index (*CI*), browning index (*BI*) and hue angle (*Hue°*) of the fresh and dried sliced apples under different drying temperatures for both infrared and hot air oven methods were calculated using equations (1) to (10) according to *Aral & Bese, (2016); Bozkir & Ergun (2020); Jafari, Movagharnejad & Sadeghi (2020).*

$$\Delta E = \sqrt{(L_O^* - L^*)^2 + (a_O^* - a^*)^2 + (b_O^* - b^*)^2} \quad (1)$$

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

$$CI = \frac{1000 \cdot a^*}{L^* \cdot b^*} \quad (3)$$

$$WI = 100 - \sqrt{(100 - L^*)^2 + a^* + b^*} \quad (4)$$

$$BI = \frac{[100(x - 0.31)]}{0.17} \quad (5)$$

$$x = \frac{(a^* + 1.75 \cdot L^*)}{(5.645 \cdot L^* + a^* - 3.012 \cdot b^*)} \quad (6)$$

$$Hue° = tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (7)$$

(when $a^* > 0$ and $b^* \geq 0; 0° < Hue < 90°$)

$$Hue° = 180 + tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (8)$$

(when $a^* < 0$ and $b^* \geq 0; 90° < Hue < 180°$)

$$Hue° = 180 + tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (9)$$

(when $a^* < 0$ and $b^* < 0; 180° < Hue < 270°$)

$$Hue° = 360 + tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (10)$$

(If $a^* > 0$ and $b^* < 0; 270° < Hue < 360°$)

where L_O^*, a_O^* and b_O^* represent the fresh samples whereas L^*, a^* and b^* represent the dried samples. According to Aral & Bese, 2016; Bagheri & Dinani, 2019; and Jafari, Movagharnejad & Sadeghi 2020, the L^* colour parameter is in 0 (blackness) to 100 (whiteness) range. The a^* parameter is from $-a^*$ (greenness) to + a^* (redness) and the b^* parameter is in $-b^*$ (blueness) to + b^* (yellowness). The chroma (*C*) indicates the colour's saturation or purity.

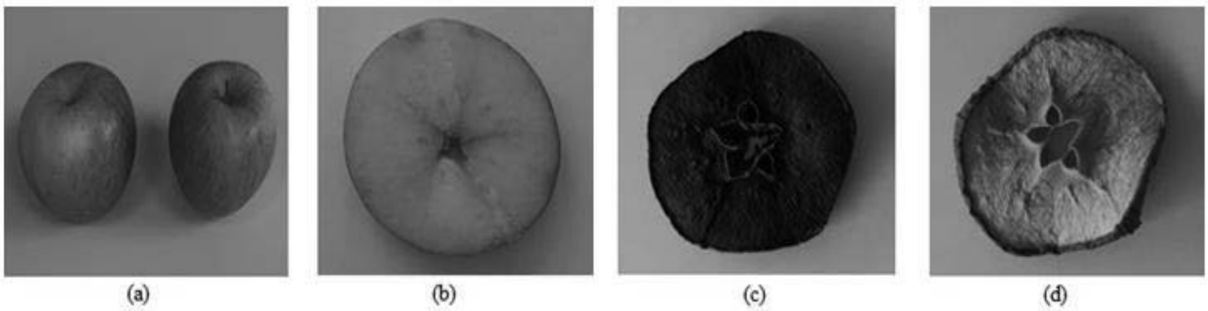

Fig. 1 Two fresh samples of whole apples (a), fresh apple slice (b), infrared dried apple slice (c) and hot air oven dried apple slice (d) at 80 °C drying temperature.

Moisture content
The moisture content MC (d.b.) of the sample during the drying process was calculated using equation (11).

$$MC = \left(\frac{W_{FS}-W_{DS}}{W_{DS}}\right) \quad (11)$$

where W_{FS} is the initial weight of the freshly sliced sample (g) and W_{DS} is the weight of the dried sliced sample (g).

Rehydration capacity
The rehydration capacity *RC* (-) was carried out according to the procedure reported by *Cui, Li, Song & Song, (2008)* cited in *Bozkir & Ergun, (2020)*. Following the procedure, the weighted dehydrated samples were dipped into a beaker of hot water at 80 °C for 15 min. The rehydrated samples were filtered over a screen for 2 min and slightly blotted with an absorbent paper thrice and then weighted again. The *RC* of the dried samples was calculated using equation (12).

$$RC = \left(\frac{W_{RS}}{W_{DS}}\right) \quad (12)$$

where W_{RS} is the weight of the rehydrated sample (g) and W_{DS} is the weight of the dried sample (g).

Shrinkage
In a drying process, the shrinkage SK (%) refers to the volume reduction or the change in selected dimensions due to the moisture removal from the sample structure (*Bozkir & Ergun, 2020*). The shrinkage of the samples was calculated using equations (13) to (15) according to *Majdi, Esfahani & Mohebbi, (2019)*.

$$SK = \left(\frac{V_O-V_f}{V_O}\right) \times 100 \quad (13)$$

where V_O is the initial volume of the fresh sample (mL) and V_f is the final volume of the dried sample (mL).

$$V_O = \pi\left(\frac{D_O}{2}\right)^2 \cdot t_O \quad (14)$$

$$V_f = \pi\left(\frac{D_f}{2}\right)^2 \cdot t_f \quad (15)$$

where D_O, t_O, D_f and t_f are the initial and final diameter (mm) and thickness (mm) of the sample.

Bulk density
The bulk density (g/mL) of the dried samples was calculated using equation (16) according to *Goula & Adamopouls, (2005)* cited in *Bozkir & Ergun, (2020)*.

$$\rho_{bulk} = \left(\frac{m}{V}\right) \quad (16)$$

where m is the weight of the dried sample (g) and V is the volume of the dried sample (mL).

Surface area
The surface area A (mm^2) of the fresh and dried sliced samples was calculated using equation (17) according to *Cetin, Saglam and Demir, (2019)*.

$$A = 2\pi r(r+h) \quad (17)$$

where r is the radius (mm) and h is the thickness (mm) of the fresh and dried samples.

Statistical analysis
The data were subjected to a correlation analysis at a 5% significance level using Statistica 13 software (*Statsoft, 2013*).

RESULTS AND DISCUSSION
The measured and calculated colour parameters of the fresh and dried sliced apple samples using the infrared (IR) and hot air oven (OV) drying methods are given in Tabs. 1 and 2. It can be seen in Tabs. 1 and 2 that the L_O^*, a_O^* and b_O^* as well as L^*, a^* and b^* values of the fresh and dried apple sliced samples increased and decreased along with the drying temperatures from 40 to 80 °C for both IR and OV. Mostly, lower values were observed at 80 °C for IR compared to OV which showed higher values.

According to *Jafari, Movagharnejad & Sadeghi (2020)*, colour is one of the major quality attributes that specifies the quality of the final product and influences consumer preference. The authors further stated that when samples of fruits and vegetables are subjected to heat treatments then non-enzymatic browning and pigment destructions can cause colour changes. In this present study, the total colour change (ΔE), chroma (ΔC), colour index (*CI*), whiteness index (*WI*) and browning index (*BI*) showed both increasing and decreasing values with the drying temperatures for IR and OV drying methods. The IR method indicated lower values among the colour indicators compared to OV. The results were similar to those reported by *Bozkir & Ergun (2020)* on persimmon cubes by ultrasound and osmotic dehydration pretreatments on the hot air drying. The correlation results (not included here) revealed that only the total colour change (ΔE) and whiteness index (WI) were significantly affected ($p < 0.05$) by the drying temperatures for IR. This means that whereas the total colour change increased along with the drying temperatures, the whiteness index decreased. Regarding the OV, the total colour change and colour index (CI) increased significantly ($p < 0.05$) with drying temperatures. The other calculated parameters as presented in Tabs. 1 and 2 for both IR and OV were not significantly affected ($p > 0.05$). Considering the rehydration capacity, it used as a measure of the physical and chemical changes that occur in the product during the drying process (*Aral & Bese, 2016*). Lower values were observed at a lower temperature of 40 ºC compared to higher temperatures from 50 to 80 ºC which recorded higher values. Similar results were reported by *Aral & Bese (2016)*. Finally, the obtained drying curves are described in Figs. 2a–2d. At all drying temperatures, higher moisture removal was observed for IR compared to the OV. For both IR and OV drying methods, the drying time of about 10 hrs was not enough to dry the sliced apple sample at 40 ºC to reach equilibrium sample weight or moisture content. The equilibrium moisture content was reached for the drying temperatures from 50 ºC to 80 ºC (Figs. 2c and d). During the drying time of about 10 hr for all drying temperatures, the moisture content values were below 6 (d.b.). *Joardder and Karim (2022)* reported similar results for apple samples during convective/hot air drying.

Tab. 1 Determined parameters of sliced apple samples dried at different temperatures using IR.

Calculated parameters	Drying temperatures 40 ºC	50 ºC	60 ºC	70 ºC	80 ºC
L_O^*	44.204	40.140	40.954	45.642	41.149
L^*	27.284	19.873	9.211	15.945	2.264
a_O^*	12.759	5.600	5.302	5.734	5.562
a^*	6.199	8.329	7.044	11.956	0.374
b_O^*	36.358	28.286	27.004	28.451	26.599
b^*	23.495	17.994	9.621	20.155	0.523
ΔE	22.244	22.894	36.233	31.456	47.105
ΔC	14.439	10.648	17.470	10.370	26.587
CI	9.670	23.292	79.486	37.203	315.859
WI	27.080	19.709	9.119	15.754	2.259
BI	172.402	200.023	270.897	385.938	37.924
$Hue°$	75.219	65.162	53.790	59.323	54.431
RC	1.542	1.798	1.676	1.772	1.616
SK	49.573	49.092	44.906	54.054	37.927
ρ_{bulk}	0.385	0.241	0.273	0.265	0.192
A_O	6833.919	8600.695	7484.533	9522.559	8347.251
A_f	4168.762	5951.719	5288.874	8957.831	8086.137
V_O	21.697	28.337	23.961	32.135	26.496
V_f	10.941	14.426	13.201	14.765	16.447

Tab. 2 Determined parameters of sliced apple samples dried at different temperatures using OV.

Calculated parameters	Drying temperatures				
	40 °C	50 °C	60 °C	70 °C	80 °C
L_O^*	28.069	46.154	47.114	42.822	48.728
L^*	24.783	34.947	24.826	16.975	19.482
a_O^*	10.112	6.601	4.661	8.031	6.391
a^*	2.651	9.154	7.41	4.519	6.596
b_O^*	22.815	30.731	28.325	29.146	30.222
b^*	20.792	27.694	21.492	24.656	17.365
ΔE	8.399	11.889	23.473	26.468	31.948
ΔC	7.730	3.968	7.364	5.700	12.859
CI	5.145	9.458	13.888	10.797	19.497
WI	24.627	34.664	24.634	16.799	19.333
BI	156.354	153.861	178.857	589.628	190.069
$Hue°$	82.734	71.709	70.977	79.614	69.201
RC	1.488	1.577	1.851	2.034	1.505
SK	52.707	57.469	50.966	55.783	53.927
ρ_{bulk}	0.434	0.468	0.344	0.331	0.344
A_O	7260.708	8429.142	7538.837	9265.871	7559.233
A_f	4626.538	5764.578	6135.093	8549.494	7039.443
V_O	21.847	25.756	24.642	30.501	24.466
V_f	10.332	10.955	12.083	13.487	11.271

IR: Infrared drying; OV: Hot air oven drying; L_O^*, a_O^* and b_O^* represent fresh samples and L^*, a^* and b^* represent dried samples as lightness, greenness/redness and blueness/yellowness; the total colour difference (ΔE), chroma (ΔC), colour index (CI), whiteness index (WI), browning index (BI); Hue angle (Hue^o); rehydration capacity RC (-); shrinkage S (%) and bulk density ρ_{bulk} (g/mL); A_O: initial area of the fresh sample (mm^2); A_f: final area of the dried sample (mm^2); V_O is the initial volume of the fresh sample (mL) and V_f is the final volume of the dried sample (mL).

CONCLUSIONS

Samples of dried apple slices were studied at different drying temperatures using infrared (IR) and hot air oven (OV) drying methods. Changes in high colour values were observed with the IR compared to the OV. Shrinkage values for OV were higher than the IR. Higher browning index values were obtained for IR compared to OV. Future studies would extend the results of the present study to obtain adequate information on the drying methods and their combinations by adopting a three-to-five factor with three levels using Box-Behnken design to optimize the quality parameters of dried fruits and/or vegetables.

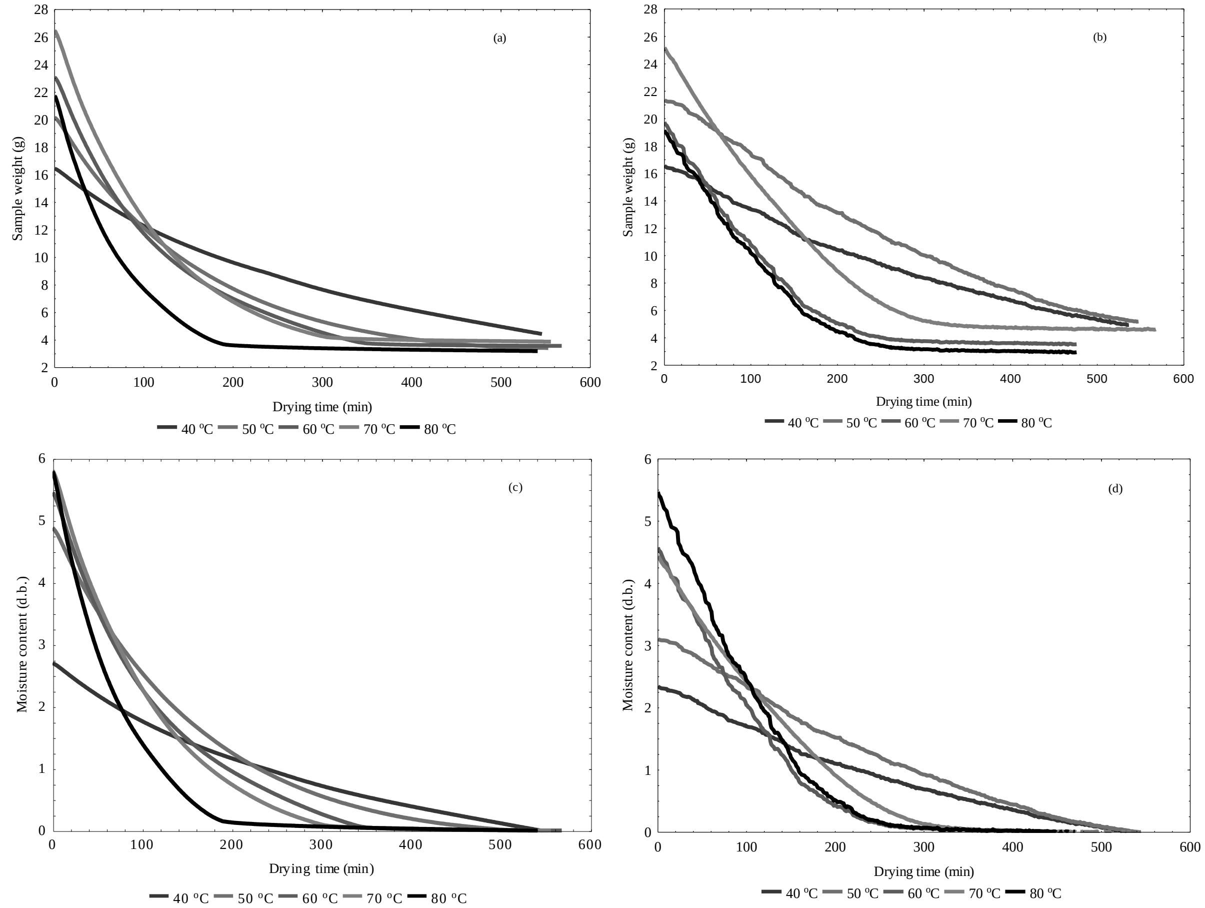

Fig. 2 Sample weight for infrared IR (a) and hot air oven OV (b) and moisture content for IR (c) and OV (d) versus drying time for different drying temperatures of a dried apple sliced samples.

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