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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Comparative Investigation of Drying and Quality Characteristics of Organic and Conventional Black Carrots Dried by Intermittent Microwave and Hot Air*

Kesikli Mikrodalga ve Sıcak Hava ile Kurutulan Organik ve Konvansiyonel Siyah Havuçların Kuruma ve Kalite Özelliklerinin Karşılaştırmalı Olarak İncelenmesi

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Abstract

The quality of agricultural crops is influenced by growing conditions and post-harvest processes, including drying. Moreover, the total phenolic and total antioxidant content in the product's structure and composition can be either positively or negatively affected by the heat treatments applied during drying. Additionally, the specific growing conditions and methods of water removal can lead to the development of distinct drying characteristics. There was no study comparing the drying kinetics and quality parameters of organic (OBC) and conventional (CBC) black carrot in the literature studies. In this study were aimed that mathematically modelling the drying kinetics for OBC and CBC with IMW (150, 300, 450 W) and HA (60, 70, 80°C), determining their differences and evaluating the effects of methods on quality properties. The results showed that L* and ΔE values of the final products increased significantly by increasing the power and temperature levels applied during drying and the powder samples were lighter in color compared to the fresh samples. The total phenolic and total antioxidant capacity values were higher in fresh OBC samples compared to the conventional variety. This result shows that OBC is superior to the CBC in terms of higher total phenolic and total antioxidant content. The activation energy (E_a) values of OBC and CBC dried by IMW and HA were calculated as $8.41\text{x}10^{-3}$; $8.40\text{x}10^{-3}$ Wg^{-1} and 25.50; 19.72 kJ mol^{-1}, respectively. The Logistic and Verma were the best fit models for describing IMW and HA drying kinetics, respectively. The samples obtained with IMW drying, which resulted in a shorter drying time, were more effect in terms of preserving and increasing the total phenolic and antioxidant content compared to dried samples with HA. The results showed that that the temperature/power levels applied to the products during the drying process, thus the drying times and the methods of removing moisture from the product are effective in the preservation of the total phenolic components.

Keywords: Drying kinetics, Activation energy, Modelling, Total phenolic, Antioxidant capacity

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Özet

Tarımsal ürünlerin kalitesi, yetiştirme koşullarından ve kurutma gibi hasat sonrası işlemlerden etkilenebilir, ayrıca ürün yapısındaki toplam fenolik ve toplam antioksidan içeriği ve bileşimi de kurutma sırasında uygulanan ısıl işlemlerden olumlu veya olumsuz yönde etkilenme potansiyeline sahiptir. Ayrıca, yetiştirme koşulları ve suyun üründen uzaklaştırılma şekli farklı kuruma özelliklerinin gelişmesine neden olabilir. Literatür çalışmaları arasında organik (OBC) ve konvansiyonel (CBC) siyah havucun kurutma kinetiği ve kalite parametrelerinin karşılaştırıldığı bir çalışmaya rastlanmamıştır. Bu çalışmada, OBC ve CBC materyallerinin kesikli mikrodalga (IMW) (150, 300, 450 W) ve sıcak hava (HA) (60, 70, 80°C) yöntemleri ile kuruma kinetiğinin matematiksel olarak modellenmesi, farklılıklarının belirlenmesi ve yöntemlerin kalite özelliklerine etkilerinin değerlendirilmesi amaçlanmıştır. Sonuçlar, kurutma sırasında uygulanan güç/sıcaklık seviyelerinin artmasıyla nihai ürünlerin L* ve ΔE değerlerinin önemli ölçüde arttığını ve toz numunelerin taze numunelere göre daha açık renkli olduğunu göstermiştir. Taze OBC örneklerinde toplam fenol ve toplam antioksidan kapasite değerleri konvansiyonel çeşide göre daha yüksek bulunmuştur. Bu sonuç, OBC'nin toplam fenolik ve toplam antioksidan içeriği açısından CBC'den daha üstün olduğunu göstermektedir. IMW ve HA ile kurutulan OBC ve CBC'nin aktivasyon enerjisi (E_a) değerleri sırasıyla 8.41×10^{-3}; 8.40x10-3 Wg^{-1} ve 25.50; 19.72 kJ mol^{-1} olarak belirlenmiştir. Logistic ve Verma modellerinin, sırasıyla IMW ve HA kurutma kinetiğini tanımlamak için en uygun modeller olduğu saptanmıştır. Daha kısa kuruma süresi ile sonuçlanan IMW kurutma ile elde edilen numunelerde, HA ile kurutulmuş numunelere göre toplam fenolik ve antioksidan içeriğin korunması ve arttırılması daha etkili olmuştur. Sonuçlar, kurutma işlemi sırasında ürünlere uygulanan sıcaklık ve güç seviyelerinin, dolayısıyla kuruma sürelerinin ve üründen nemi uzaklaştırma yöntemlerinin toplam fenolik bileşenlerin korunmasında etkili olduğunu göstermiştir.

Anahtar Kelimeler: Kurutma kinetiği, Aktivasyon enerjisi, Modelleme, Toplam fenolik, Antioksidan kapasite.

1. Introduction

Drying, which is also classified as a food preservation method, can be defined as the process of removing excess water from the product, which causes the development of negative properties in the products after a certain period of time. The way of water removed from food products (Esturk et al., 2011), drying methods (Soysal, 2004), drying temperature or power levels (Arslan, 2021), growing conditions of products (Asami et al., 2003; Arslan et al., 2020a; Guilherme et al., 2020), maturity stages (Soysal et al., 2018), thickness (Sadin et al., 2014), air flow rate (Velić et al., 2004), drying time (Soysal, 2004; Arslan et al., 2021), properties of the material, freshness and many other factors causes the development of different quality characteristics in final products. Determining drying conditions that affect the quality of the final products as positively or negatively and to verify the effectiveness of the conditions with experimental methods are important.

By using modern drying methods, a higher quality and more valuable final products in terms of health is obtained compared to traditional methods (Soysal, 2004). In hot air (HA) drying, there is a gradual transfer of heat from the material surface to the interior due to the temperature difference between the hot surface and the colder interior of the material (Arslan et al., 2020b). In the microwave (MW) drying method, the electromagnetic field affects the whole material and the water molecules in the material are directly targeted (Soysal et al., 2006), thus a selective heating is performed resulting in a shorter drying time. As a result of the application of continuous MW energy, some negative quality characteristics such as burns in the material and hardening on the product surface (Soysal, 2004) develop as a result of high temperature/power applied to the dried material. With intermittent microwave (IMW) drying, the development of undesirable properties is reduced and more homogeneous heat and mass transfer is allowed (Soysal, 2009).

The cultivation of agricultural practices can affect the phytochemical content, structure, taste, aroma, color and thus drying properties of the products (Asami et al., 2003; Keskin et al., 2021a; Arslan, 2022). Bickel and Rossier (2015) reported that organic products are more nutritious than conventional varieties. Guilherme et al. (2020) stated that chlorogenic acid, caffeic acid and rutin were found in higher levels in red organic peppers. Arslan (2021) reported that organic black carrot (OBC) as fresh and dried by IMW are superior to its conventional (CBC) variety in terms of total phenolic and total antioxidant capacity. Phenolic compounds in fruits and vegetables are natural antioxidants that have the ability to reduce and remove the negative properties of free radicals (Sonmezdag, 2015). During the application of heat treatments, the nutritional value of the food decreases significantly due to the destruction of heat-sensitive phenolic components (Choi et al., 2006). However structure and composition of the foods and the applied heat treatments may cause an increase or decrease in the amount of phenolic compounds (Sakač et al., 2011), antioxidants (Meral, 2016) and color (Aktaş et al., 2013; Keskin et al., 2019; Arslan et al., 2023) properties. Keskin et al. (2021b) found that the highest amounts of phenolic were in the black carrot samples dried by HA and IMW compare to freeze drying. Therefore, evaluating of the effects of drying methods and applied temperature/power levels on the total phenolic compounds naturally found in food and the total antioxidant capacity are important.

Black carrot (*Daucus carota* L. ssp. *sativus* var. *Atrorubens* Alef.) commonly is used in powder form as a colouring additive, dietary fiber source, phenolic and antioxidant component of different dried and liquid products (Janiszewska et al., 2013) and have a high potential as a food colorant due to their low toxicity (Ersus & Yurdagel, 2007). The quality of black carrot obtained by applying various cultivation methods such as organic or conventional is likely to be affected by these conditions. Therefore, it may be beneficial for the sector to determining the drying resistance of the product types for the same drying power/temperature and to determine the effects of these conditions on product quality. Further, evaluation of the effects of drying methods on drying kinetics, quality and color parameters can be useful in terms of predicting of final product quality. In the literature studies, there was no studies comparing the drying kinetics, color parameters and quality of OBC and CBC of dried by IMW and HA drying methods. Therefore, this study was carried out to evaluating effects of drying OBC and CBC samples at different power and temperature levels with IMW and HA, their drying kinetics, moisture diffusion characteristics, mathematical models, effects on color, total phenolic and antioxidant capacities. This study is the first research in literature which the drying characteristics and pre- and post-drying quality parameters of organic and same variety conventional black carrots are examined.

2. Materials and Methods

2.1. Black carrot samples

OBC and CBC samples (Eregli local cultivar) were obtained from open field conditions (Eregli, Konya Turkey) (37.7458°N, 33.9254°E). Harvested samples were classified according to their size and color properties, they were stored in the refrigerator at +4°C until drying stage. The initial moisture content determined by standard oven method (103°C for 24 h) of the OBC and CBC samples were about 87.8% and 88.1%, respectively.

While preparing the samples for the drying stage, they were firstly washed with tap water, removed moisture with filter paper and grated by using a grater to provide a certain thickness level (Tefal, MB753538). The samples were spread homogeneously on the glass table (diameter: 30 cm, mass: 1150 g) surface and the product mass was adjusted as approximately 250 g. Average half layer thickness of the samples over the glass tray surface (6.4±0.50 mm) and average grated material slice thickness (1.4±0.13 mm) were measured.

2.2. Intermittent microwave drying process

A lab-scale (MD 1605, Beko, Istanbul, Turkey; nominal power: 2.45 GHz, 900 W) microwave oven was used in the IMW drying experiments (Actual power: 735.8±8.12 W; the size of MW oven cavity: 22x35x33 cm). The experiments were carried out by varying the IMW open (T_{on}) and close (T_{off}) times at different power levels (150, 300 and 450 W) and controlled by a Programmable Logic Controller (PLC) according to the method applied by Arslan et al. (2020a) (airflow speed: 1.5 ms^{-1}).

2.3. Hot air drying process

The HA consists of three main units, an electrical resistance based air heater, a radial fan and a drying chamber. With the software created by using the Arduino UNO card, the heating resistors were automatically turned off when the temperatures in the cabinet exceed the determined level (60, 70, 80°C) and automatically turned on when the temperature falls below the determined temperature levels, and the determined drying temperatures are obtained (airflow speed: 1.25 - 1.50 ms^{-1}).

The drying procedure was repeated five times at each of the three IMW power (OBC: 15; CBC: 15) and temperature (OBC: 15; CBC: 15) levels, and a total of 60 drying experiments were performed.

Digital balance (Sartorius TE3102S Germany, 3100, accuracy: 0.01 g) was placed under the rotating glass tray to measure the mass of materials and the temperature in each drying method were recorded one minute intervals. All experiments were lasted when the samples reached a moisture level of about 0.10 kg [H2O] kg^{-1} [DM]. Fresh and dried black carrot samples was given in *Figure 1*. The dried samples were powdered with an electric grinder (BlueHouse, BH258CG).

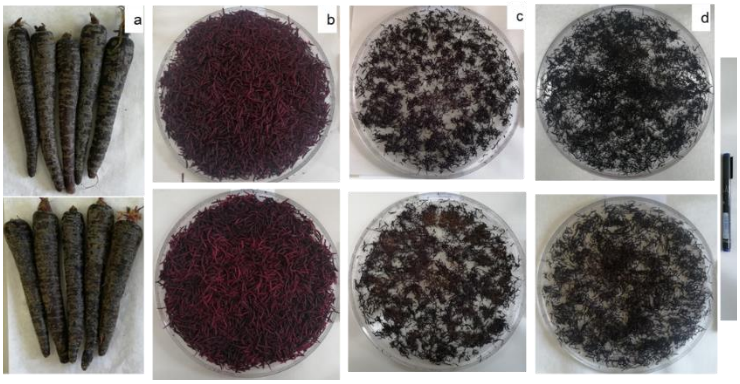

Figure 1. Organic (above), conventional (below) black carrot samples; whole (left) (a), fresh grated samples (b), dried by intermittent microwave (c) and dried by hot air (d)

2.4. Analysis of color parameters

The color properties of carrot samples was measured with a handheld colorimeter (Minolta CR - 400, Osaka, Japan) using the CIE L*a*b* color model. The meanings of L*, a* and b* parameters are color brightness, red-green and yellow-blue, respectively. The color difference (ΔE^*) and was calculated as according to Soysal et al. (2018).

2.5. Determining of total phenolic and total antioxidant capacity

The total phenolic content of the samples was determined according to the method applied by Singleton and Rossi (1965). 1 ml of each sample extract was mixed with 60 ml of distilled water, 5 ml of Folin-Ciocalteu solution and 15 ml of sodium bicarbonate solution and left for 2 hours at 25°C. Total phenolic content was measured at 765 nm with a UV-VIS field spectrophotometer (Agilent, Cary 60 UV-VIS, USA). The amount of phenolic compound, which is the gallic acid equivalent of the measured absorption value, was calculated from the equation of the standard curve prepared with gallic acid. Total phenolic content was calculated in "mg gallic acid/kg".

There are different methods for the analysis of total antioxidant capacity of the samples. Although each method has advantages and disadvantages, the success of the analysis method to be chosen may vary according to the material kinds. For example, the DPPH (2,2-diphenyl-1-picrylhydrazil) method; since it is sensitive to light, oxygen and pollution factors, there may be certain limitations in the use of this method (Mot et al., 2011). Therefore, the antioxidant activities of the samples were determined according to DPPH and ABTS (2,2'-Azino-bis 3-ethylbenzothiazoline-6-sulfonic acid) methods.

Evaluating of the antioxidant capacity for DPPH and ABTS were determined at 515 nm (Brand-Williams et al., 1995) and 734 nm (Saafi et al., 2009) in the UV-VIS field spectrophotometer, respectively. Absorbance values were calculated with the Trolox standard slope chart and the results were determined in μmol/100g Trolox.

2.6. Mathematical modeling of drying curves

The data were fitted to various drying models to determine the best fitting drying equation. In the evaluation, the equilibrium moisture content (M_e), was assumed to be zero, and the Moisture ratio (MR) were simplified as M/M_0 (Doymaz and Pala, 2002). The equations of the models are calculated as Arslan et al. (2020a).

Where,

M_e: Equilibrium moisture content (kg [H_2O] kg^{-1} [DM]),

M: The moisture content at any time during drying (kg [H_2O] kg^{-1} [DM])

M_0: The initial moisture (kg [H_2O] kg^{-1} [DM]) correspond to their meaning.

Nonlinear regression models were applied with Sigma Plot (10.0) program (Version 12; Systat Software, San Jose, CA, USA). The statistical values of R^2 (the coefficient of determination), RSS (residual sum of squares) (Equation 1) and SEE (standard error of estimate) (Equation 2) were calculated to select the best models. These parameters were computed as follows:

$$\mathrm{RSS}=\sum_{i=1}^{N}\left(\mathrm{MR}_{\mathrm{exp,i}}-\mathrm{MR}_{\mathrm{Pre,i}}\right)^2 \qquad \text{Eq. (1)}$$

$$\mathrm{SEE}=\sqrt{\frac{\sum_{i=1}^{N}(\mathrm{MR}_{\mathrm{exp,i}}-\mathrm{MR}_{\mathrm{pre,i}}}{\mathrm{N-2}}} \qquad \text{Eq. (2)}$$

In equations; $MR_{exp,i}$: experimental drying rate and $MR_{pre,i}$: estimated drying rate and N represents the number of data.

2.7. Effective diffusivity and activation energy

The effective moisture diffusivity (D_{eff}) was calculated with Equation 3 using the second Fick's diffusion equation given below (Crank, 1975):

$$\mathrm{MR}=\frac{\mathrm{M-M_e}}{\mathrm{M_0-M_e}}=\frac{8}{\pi^2}\sum_{i=0}^{\infty}\frac{1}{(2i+1)}\exp\left[\frac{(2i+1)^2\pi^2 D_{\mathrm{eff}}\,t}{4L^2}\right] \qquad \text{Eq. (3)}$$

In equation, D_{eff}, L, i and t values represent the effective moisture diffusivity (m^2s^{-1}), half thickness of the samples layer over the glass tray surface (m), positive integer and time (s), respectively. Equation 3 is simplified as in Equation 4 (Wang et al., 2007):

$$\ln(\mathrm{MR})\frac{8}{\pi^2}\text{-}\frac{\pi^2 \mathrm{D_{eff}}}{4\mathrm{L}^2}\mathrm{t} \qquad \text{Eq. (4)}$$

The D_{eff} values, were calculated by plotting experimental ln(MR) data against drying time, so the plot provides a straight line with a slope as $K=\pi^2 D_{eff}/4L^2$.

In the study, the D_{eff} values, on the ratio of applied IMW power to fresh sample mass were characterized with an Arrhenius-type exponential model Equation (Dadali et al., 2007) (Equation 5) for IMW method.

$$\mathrm{D_{eff}}=\mathrm{D_0}\exp(\text{-}\mathrm{E_a}\ \mathrm{m}/\mathrm{P_a}) \qquad \text{Eq. (5)}$$

Where, E_a is activation energy (Wg^{-1}), P_a is applied IMW power and m is mass of initial fresh samples. Then, the E_a was computed from the slope of the Equation 5 by plotting ln(D_{eff}) versus m/P_a.

The HA temperature dependency of the D_{eff} was predicted by using an Arrhenius type equation (Doymaz and Ismail, 2011) (Equation 6) for HA method:

$$\mathrm{D_{eff}}=\mathrm{D_0}\exp(\text{-}\mathrm{E_a}/\mathrm{RT}) \qquad \text{Eq. (6)}$$

Where, E_a is activation energy (kJ mol^{-1}), R is the universal gas constant ($8.3143x10^{-3}$ kJ mol^{-1}), T is applied absolute temperature (K). Then, the E_a was calculated from the slope of the Equation 6 by plotting ln(D_{eff}) versus 1/T ($K_1=E_a/R$) for HA.

2.8. Statistical analysis

18 Fresh (OBC: 9; CBC: 9) and 60 dried-powdered OBC (HA: 15; IMW: 15) and CBC (HA: 15; IMW: 15) samples (three power and three temperature levels multiplied by five drying experiments) were included in color analysis. The effects of drying power and temperature levels on the color of dried-powdered OBC and CBC were examined with statistical software (SPPS, v.17, IBM, NY, USA) using one way of variance (ANOVA) and the means compared with Duncan's test ($p<0.05$).

The effect of drying power and temperature levels on the total phenolic (OBC: 3, CBC: 3) and total antioxidant (for DPPH and ABTS) capacity results of dried 6 OBC (HA: 3; IMW: 3) and 6 CBC (HA: 3; IMW: 3) were examined with ANOVA and their means compared with Duncan's test ($p<0.05$). Fresh OBC and CBC samples results of total phenolic and total antioxidant capacity were compared with the values of dried samples in the same analysis.

3. Results and Discussion

3.1. Effect of drying methods on color properties

Information of color parameters of OBC and CBC materials, fresh and dried by IMW and HA and after powdered, are given in *Table 1* and *Table 2*, respectively. The means of L*, a* and b* color parameters of fresh OBC and CBC were calculated as 25.48±0.48, 4.31±0.87, 0.884±0.28 and 21.35±0.76, 5.15±1.21, 1.91±0.38, respectively. The mean L* and b* value differences of fresh samples were significant ($p<0.001$). The color brightness (L*) and color difference (ΔE*) values of the final product were increased significantly increasing with the applied IMW power and HA temperature levels during drying and the dried-powdered samples were lighter in color compared to the fresh samples ($p<0.05$). The a* values of samples dried by IMW were significantly higher than the fresh ones ($p<0.05$) and decreased with increasing power level. Consequently, statistical analysis showed that applied temperature and power levels were a crucial factor on color parameters of the powdered carrots. The color of carrot samples dried at high applied temperature (70, 80°C) and power levels (300 W, 450 W) were comparatively brighter and more vivid blueness-red and increase of applied temperature levels.

Research findings were compared with literature studies. Similarly, Demiray (2015) determined that the b* value was significantly affected by the drying methods and conditions during the drying process of carrots ($p<0.05$). Polat et al. (2022) investigated that dried by convective and microwave drying on color properties of black carrot pomace and founded that convective drying resulted in higher L* and ΔE values but lower a* and b* values compared to dried samples by MW drying. Contrary to the results of this study, Talih et al. (2017) reported that the L* of the black carrot powders decreased with applied increasing MW powers. Keskin et al. (2021b) founded that HA and IMW drying of black carrot samples resulted in a decrease in the b* value while increasing the L* and a* values.

Table 1. Color parameters of samples fresh and dried with intermittent microwave powers

Parameters	**Product**	**Fresh**	**Dried at 150 W**	**Dried at 300 W**	**Dried at 450 W**
L*	OBC	25.48±0.48^{b}	36.13±0.60^{c}	37.95±0.41^{d}	39.94±0.40^{e}
	CBC	21.35±0.76^{a}	39.51±0.95^{e}	41.97±0.50^{f}	44.70±0.45^{g}
a*	OBC	4.31±0.87^{a}	15.19±0.60^{f}	14.48±1.04^{ef}	12.20±0.66^{c}
	CBC	5.15±1.21^{a}	13.82±1.01^{de}	12.80±1.25^{cd}	10.72±1.10^{b}
b*	OBC	0.88±0.28^{c}	-0.48±0.40^{a}	-0.56±0.17^{b}	4.40±1.29^{e}
	CBC	1.91±0.38^{d}	-0.38±0.11^{b}	1.71±0.29^{d}	7.77±1.80^{f}
ΔE	OBC	-	15.42±0.44^{a}	16.17±0.70^{ab}	16.90±0.36^{b}
	CBC	-	20.72±0.95^{c}	22.50±0.82^{d}	25.35±0.60^{e}
Total Phenolic (mg/100g GAE)	OBC	903.0±0.87^{c}	1246.0±1.17^{f}	1075.9±0.56^{d}	1752.5±1.77^{h}
	CBC	865.8±0.58^{b}	732.5±1.84^{a}	1205.4±2.29^{e}	1346.3±0.72^{g}
AA, DPPH (µmol Trolox/100 g)	OBC	427.4±5.87^{bc}	645.5±15.98^{d}	462.3±5.02^{c}	664.5±13.01^{d}
	CBC	269.9±0.21^{a}	287.1±25.10^{a}	406.1±10.04^{b}	796.5±41.30^{e}
AA, ABTS (µmol Trolox/100 g)	OBC	314.3±5.59^{b}	772.3±4.38^{e}	734.9±35.50^{e}	853.3±18.81^{f}
	CBC	309.8±13.86^{b}	257.0±15.13^{a}	615.9±2.76^{c}	681.0±4.70^{d}
Drying Time (min)	OBC	-	103.0±0.0^{a}	50.0±0.0^{b}	35.0±0.0^{c}
	CBC	-	100.0±0.0^{a}	50.0±0.0^{b}	35.0±0.0^{c}

(OBC: Organic; CBC: Conventional; GAE: Gallic Acid Equivalent). Different letters on the same two rows for each parameter indicate that the difference between the means is significant ($p<0.05$).

Table 2. Color parameters of samples fresh and dried with hot air temperatures

Parameters	**Product**	**Fresh**	**Dried at 60°C**	**Dried at 70°C**	**Dried at 80°C**
L*	OBC	25.48±0.48^{b}	37.23±0.83^{c}	39.38±0.21^{d}	41.00±0.44^{e}
	CBC	21.35±0.76^{a}	39.22±0.30^{d}	40.39±0.74^{e}	42.91±1.18^{f}
a*	OBC	4.31±0.87^{a}	14.65±0.46^{e}	13.48±0.74^{cd}	13.97±0.40^{de}
	CBC	5.15±1.21^{a}	12.29±0.22^{b}	13.00±0.63^{bcd}	12.75±0.54^{bc}
b*	OBC	0.88±0.28^{c}	0.49±0.05^{c}	-0.35±0.13^{b}	-1.70±0.05^{a}
	CBC	1.91±0.38^{d}	3.58±0.20^{f}	2.05±0.49^{e}	0.95±0.05^{d}
ΔE	OBC	-	15.70±0.80^{a}	16.71±0.45^{b}	18.50±0.51^{c}
	CBC	-	19.80±0.32^{d}	21.10±0.25^{e}	23.37±1.21^{f}
Total Phenolic (mg/100g GAE)	OBC	903.0±0.87^{c}	878.2±0.35^{d}	1028.4±1.45^{g}	1111.9±1.04^{h}
	CBC	865.8±0.58^{b}	517.8±1.28^{a}	698.9±4.52^{b}	993.2±1.29^{f}
AA, DPPH (µmol Trolox/100 g)	OBC	427.2±5.87^{bc}	289.0±12.72^{bc}	330.9±7.21^{d}	380.9±4.03^{e}
	CBC	269.9±0.21^{a}	297.4±9.76^{c}	142.3±6.36^{a}	495.8±23.69^{g}
AA, ABTS (µmol Trolox/100 g)	OBC	314.3±5.59^{b}	386.5±34.44^{d}	424.8±1.84^{e}	376.2±0.35^{d}
	CBC	309.8±13.86^{b}	247.8±0.42^{b}	193.6±3.04^{a}	601.0±16.69^{f}
Drying Time (min)	OBC	-	170.0±0.0^{a}	128.0±0.0^{b}	112.0±0.0^{c}
	CBC	-	170.0±0.0^{a}	135.0±0.0^{b}	113.0±0.0^{c}

(OBC: Organic; CBC: Conventional; GAE: Gallic Acid Equivalent). Different letters on the same two rows for each parameter indicate that the difference between the means is significant ($p<0.05$).

3.2. Effect of drying methods on total phenolic and antioxidants

Phenolic compounds are natural antioxidants that have the ability to reduce and eliminate negative properties of free radicals (Sonmezdag, 2015) also total phenolic compounds are secondary metabolites responsible for the colour, taste and aroma properties of fruits and vegetables (Meral, 2016).

Total phenolics content of fresh OBC and CBC samples were calculated as 903 and 866 mg/100g, respectively. The total phenolic content of OBC and CBC samples dried by applying 150, 300 and 450 W power with IMW were 1246, 1076, 1752 and 732, 1205, 1346 mg/100g GAE, respectively (*Table 1*). Applied all drying power levels caused an increase in total phenolic content compared to fresh samples. According to the DPPH method, the antioxidant activity values of OBC and CBC samples dried at 150, 300 and 450 W were calculated as 646, 462, 665 and 287, 406, 796 µmol Trolox/100 g, respectively (*Table 1*). Power of 450 W drying resulted in the highest antioxidant activity for both product types.

The total phenolic content of OBC and CBC samples dried at 60, 70 and 80°C with HA was found to be 878, 1028, 1112 and 518, 699, 933 mg/100g GAE, respectively (*Table 2).* The antioxidant activity values of fresh OBC and CBC samples for DPPH were calculated as 427 and 270 µmol Trolox/100 g (*Table 2*). In DPPH and ABTS methods, the highest antioxidant capacity values were determined for OBC samples. According to the results of this study, it can be said that 80°C drying temperature is suitable for obtaining high total phenolic compound and antioxidants.

The total phenolic values obtained from the samples dried at 80°C and 150 W power level are close to each other. It can be said that the reason for this may be related to the fact that the drying times are close to each other (for OBC and CBC, respectively 80°C: 112-113 min; 150 W: 103-100 min). It can be said that the drying time decreased with the applied high drying temperature (80°C) and power (450 W), and accordingly, the final product color brightness (L*) and color difference (ΔE) values, total phenolic and total antioxidant values increased compared to fresh.

During product processing such as heat treatments, antioxidants naturally found in food may be destroyed and new components with antioxidant activity may be formed (Meral, 2016). The IMW power levels applied during drying increased the total antioxidant value of the product compared to the fresh ones according to DPPH method. Similarly, Choi et al. (2006) reported that there may be an increase in the amount of phenolic compounds compared to fresh ones due to the release of phenolic compounds after heat treatments. Calligaris et al. (2004) stated that the level and time of the applied heat procedure can change the antioxidant properties. Turkmen et al. (2005) reported that heat treatments caused a significant increase in the antioxidant activity of broccoli, peppers, green beans and spinach. Contrary to results of this study, Polat et al. (2022) investigated the effects of drying methods on the phenolic and volatiles of black carrot pomace and reported that drying reduces the amount of colorless phenolic. Guilherme et al. (2020) was determined that fresh conventional pepper samples had higher phenolic-antioxidant levels compared to organic samples.

3.3. Evaluating of drying kinetics

The time-dependent moisture content of OBC and CBC samples dried by using IMW and HA method are given in *Figure 2*. Increasing with the applied power and temperature significantly decreased the drying time ($p<0.05$). Although there is no distinctive difference in terms of drying OBC and CBC due to may be the material type is the same, it is seen that the drying methods and the applied power/temperature levels make a significant difference. Increasing with applied temperature and power levels, the product types demonstrated the same drying resistance to the same drying methods.

Drying rate tends to be stable in the early stages of the drying process both IMW and HA methods (*Figure 3*). The drying process for both OBC and CBC samples occurred mainly in the period of decreasing rate after a short warm-up period for HA.

The research findings were compared with the literature studies examining the differences between organic and conventional samples. Similarly, Arslan et al. (2020b) in a similar study compared the IMW drying kinetics of organic and conventional pepper, supports this result. Although the IMW and HA drying methods do not reveal a distinctive difference for the product types, it is clearly seen that the methods affect the way moisture is removed from the products. With lasted long time drying, heat and power are applied to the products for a longer time and this may also lead to the development of some undesirable features (Soysal et al., 2006). It can be said that the use of IMW and 300 and 450 W power levels for drying OBC and CBC samples were more economical in terms of lasted drying time.

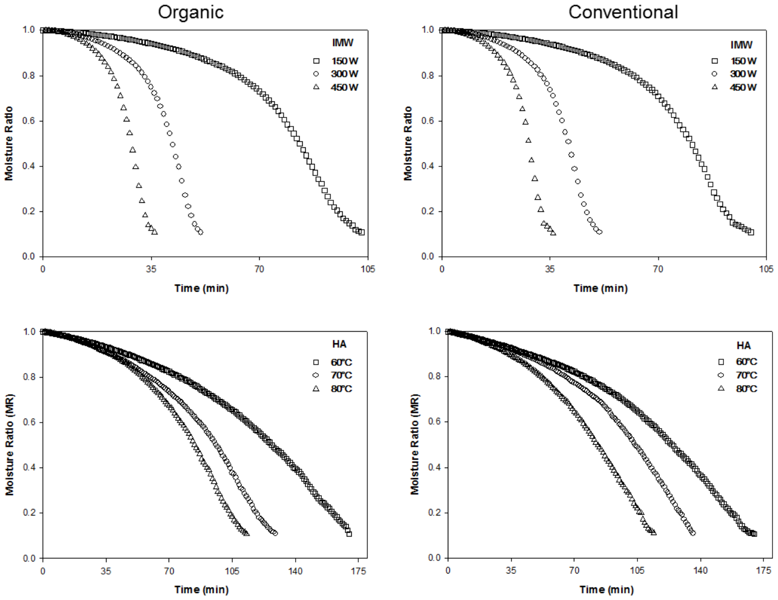

Figure 2. Moisture ratio change as a function of drying power/temperature of samples dried with intermittent microwave (IMWD) and hot air (HAD) drying

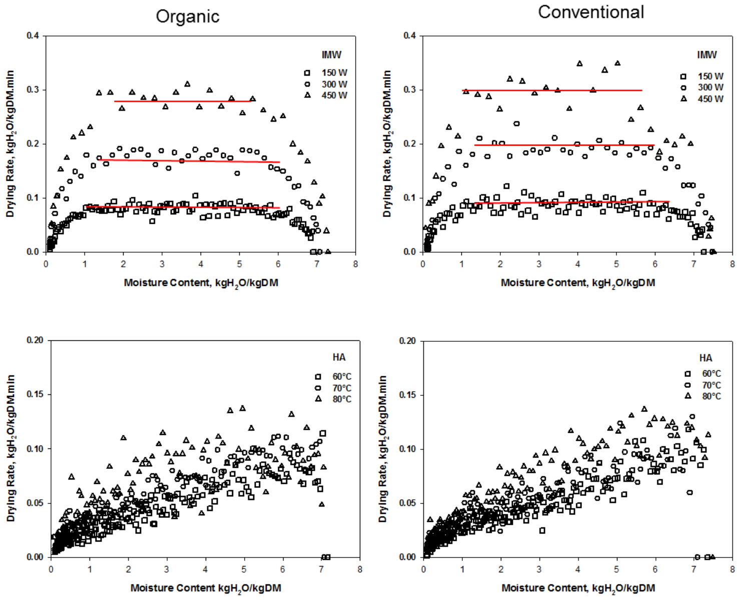

Figure 3. Variation of drying rate as a function of moisture content of dried samples by using intermittent microwave (IMW) and hot air (HA)

3.4. Modeling of drying curves

During the IMW and HA methods, the experimental moisture contents on the basis of dry weight were converted into humidity ratio (MR) values at different times and fitted against the drying time. In the study, the formulas and details of the models employed for drying kinetics were presented by Arslan et al. (2020a). For dried samples by IMW, the best fitting model for both OBC and CBC samples was the Logistic model (Model 7) with the values for the R^2 greater than 0.9918, the SEE of lower than 0.0255 and the RSS of lower than 0.0639 (Table 3). But, Verma model, it can be said that more accurate predictions can be made for OBC samples dried at 150 and 300 W compared to the Logistic model. For dried samples by HA, the best fitting model for both OBC and CBC samples was the Verma model (Model 9) with the values for the R^2 greater than 0.9975, the SEE of lower than 0.0142 and the RSS of lower than 0.0223 (*Table 3*).

Table 3. Fitting ability of eleven drying models for the intermittent microwave and hot air drying of organic and conventional samples

Product	**Model No**	**IMWD at 150 W**			**IMWD at 300 W**			**IMWD at 450 W**			**HAD at 60°C**			**HAD at 70°C**			**HAD at 80°C**		
		R²	**SEE**	**RSS**	**R²**	**SEE**	**RSS**	**R²**	**SEE**	**RSS**	**R²**	**SEE**	**RSS**	**R²**	**SEE**	**RSS**	**R²**	**SEE**	**RSS**
OBC	1	0.6230	0.1631	29.439	0.6056	0.1736	15.067	0.6153	0.1849	11.961	0.7887	0.1192	24.145	0.7633	0.1328	22.579	0.7410	0.1422	22.641
	2	0.9447	0.0650	0.4316	0.9868	0.0320	0.0503	0.9704	0.0521	0.0922	0.9845	0.0324	0.1776	0.9836	0.0351	0.0012	0.9891	0.0293	0.0954
	3	0.7139	0.1480	22.345	0.6971	0.1537	11.570	0.7064	0.1639	0.9129	0.8521	0.1000	16.898	0.8303	0.1129	0.0127	0.8164	0.1203	16.057
	4	0.8165	0.1191	14.326	0.7981	0.1267	0.7711	0.8176	0.1311	0.5672	0.9392	0.0643	0.6951	0.9251	0.0753	0.7146	0.9157	0.0819	0.7374
	5	0.9057	0.0947	0.4214	0.8897	0.1709	13.727	0.9043	0.0964	0.2976	0.9788	0.0380	0.2417	0.9723	0.0460	0.2645	0.9698	0.0492	0.2638
	6	0.9418	0.0667	0.4544	0.9757	0.0435	0.0928	0.9820	0.0406	0.0561	0.9985	0.0100	0.0170	0.9970	0.0150	0.0286	0.9974	0.0144	0.0230
	7	0.9926	0.0239	0.0577	0.9918	0.0255	0.0313	0.9954	0.0208	0.0142	0.9932	0.0215	0.0775	0.9927	0.0235	0.0699	0.9951	0.0198	0.0430
	8	0.8684	0.1014	10.276	0.8576	0.1076	0.5439	0.9888	0.033	0.0349	0.9501	0.0584	0.5704	0.9376	0.0690	0.5952	0.9351	0.0721	0.5672
	9	0.9930	0.0232	0.0545	0.9932	0.0233	0.0261	0.9885	0.0329	0.0358	0.9997	0.0045	0.0033	0.9982	0.0117	0.0174	0.9975	0.0142	0.0223
	10	0.8424	0.1098	12.305	0.9017	0.0110	0.0059	0.9774	0.0454	0.0702	0.8814	0.0896	13.555	0.9960	0.0174	0.0385	0.9926	0.0241	0.0645
	11	0.8542	0.1062	11.382	0.8443	0.1113	0.5948	0.8557	0.1166	0.4486	0.9429	0.0623	0.6522	0.8666	0.1005	12.719	0.7410	0.1435	22.642
CBC	1	0.6127	0.1734	30.076	0.6075	0.1800	16.193	0.6124	0.1919	12.889	0.7771	0.1276	27.669	0.7605	0.1273	21.874	0.7786	0.1287	18.724
	2	0.9794	0.0402	0.1603	0.9861	0.0342	0.0572	0.9914	0.0290	0.0287	0.9829	0.0355	0.2128	0.9822	0.0348	0.1626	0.9900	0.0275	0.0849
	3	0.7037	0.1524	23.006	0.6997	0.1590	12.390	0.7026	0.1705	0.9889	0.8395	0.1086	19.923	0.8276	0.1084	15.743	0.8473	0.1074	12.918
	4	0.8067	0.1238	15.011	0.8066	0.1289	0.7977	0.8179	0.1355	0.6057	0.9341	0.0698	0.8187	0.9189	0.0746	0.7404	0.9408	0.0671	0.5003
	5	0.9003	0.0893	0.7739	0.8967	0.0952	0.4263	0.9034	0.1002	0.3214	0.9760	0.0423	0.2982	0.9677	0.0472	0.2945	0.9814	0.0378	0.1573
	6	0.9755	0.0439	0.1904	0.9780	0.0430	0.0906	0.9778	0.0466	0.0738	0.9977	0.0130	0.0286	0.9964	0.0158	0.0333	0.9993	0.0070	0.0055
	7	0.9918	0.0255	0.0639	0.9943	0.0222	0.0237	0.9949	0.0226	0.0169	0.9932	0.0224	0.0845	0.9810	0.0361	0.1734	0.9958	0.0180	0.0359
	8	0.9878	0.0313	0.0951	0.9901	0.0295	0.0409	0.9816	0.0437	0.0610	0.9418	0.0658	0.7223	0.9364	0.0664	0.5813	0.9519	0.0608	0.4069
	9	0.9910	0.0267	0.0701	0.9897	0.0298	0.0427	0.9814	0.0432	0.0617	0.9989	0.0088	0.013	0.9994	0.0064	0.0055	0.9985	0.0106	0.0124
	10	0.7008	0.1532	23.236	0.9820	0.0389	0.0742	0.9678	0.0561	0.1071	0.9973	0.0141	0.0334	0.9983	0.0107	0.0154	0.9950	0.0194	0.0423
	11	0.8456	0.1106	11.989	0.8472	0.1146	0.6302	0.8513	0.1224	0.4944	0.8807	0.0939	14.806	0.9278	0.0704	0.6597	0.8816	0.0950	10.015

(OBC: Organic; CBC: Conventional; HAD: Hot Air Drying; IMWD: Intermittent Microwave Drying.) (Arslan et al. (2020a) provided the model numbers and names as follows; 1: Newton; 2: Page; 3: Henderson and Pabis; 4: Logarithmic; 5: Midilli; 6: Wang and Singh; 7: Logistic; 8: Two term; 9: Verma; 10: Two term exponential; 11: Diffusion approximation)

Information on the model constant values obtained is given in *Table 4* for IMW and HA drying methods. The drying coefficient (k) increased with increasing with at applied IMW power and HA temperatures.

Table 4. Logistic and Verma model constants of samples dried by intermittent microwave and hot air

Product	Drying Power (W)	Logistic Model Constant			Drying Temperature (°C)	Verma Model Constant		
		Intermittent Microwave				Hot Air		
		k	***a***	***b***		***k***	***a***	***b***
OBC	150	0.0882	0.0007	0.9678	60	-0.0022	17.282	-0.0070
CBC		0.0949	0.0005	0.9664		-0.0023	17.304	-0.0072
OBC	300	0.1883	0.0005	0.9705	70	-0.0025	14.592	-0.0113
CBC		0.1919	0.0005	0.9724		-0.0030	12.458	-0.0130
OBC	450	0.2705	0.0006	0.9763	80	-0.0055	24.881	-0.0100
CBC		0.2852	0.0005	0.9743		-0.0038	18.856	-0.0102

(OBC: Organic; CBC: Conventional)

3.5. Effective moisture diffusivity and activation energy

The effective moisture diffusivity (D_{eff}) and activation energy (E_a) values for the OBC and CBC samples dried with three different IMW powers and HA temperatures were given in *Table 5*. D_{eff} values of OBC and CBC samples dried by IMW were calculated as ranged from 4.29x10^{-9} to 13.39x10^{-9} m^2s^{-1} and 4.50x10^{-9} to 14.8 x10^{-9}

m^2s^{-1} respectively. No statistically significant difference was observed between the D_{eff} values of OBC and CBC dried by IMW except for 450 W. D_{eff} values of OBC and CBC samples dried by HA were found to vary between 2.59x10^{-9} to 4.36x10^{-9} m^2s^{-1} and 2.82x10^{-9} to 4.24x10^{-9} m^2s^{-1}, respectively, depending on the applied temperature level. Difference between the D_{eff} values of OBC and CBC dried by applying 60 and 80°C temperature levels was not statistically significant, but the difference was significant for the samples dried by applying 70°C.

Table 5. Effective moisture diffusivity (D_{eff}) coefficients, Activation Energy (E_a) values of samples

Product	Drying Power (W)	Intermittent Microwave			Drying Temperature (°C)	Hot Air		
		D_{eff} (x10^{-9} m^2s^{-1})	D_0 (x10^{-8} m^2s^{-1})	E_a (x10^{-3} Wg^{-1})		D_{eff} (x10^{-9} m^2s^{-1})	D_0 (x10^{-6} m^2s^{-1})	E_a (kJ mol^{-1})
OBC	150	4.29±0.43^a			60	2.59±0.23^a		
CBC		4.50±0.20^a	2.24	8.41		2.82±0.13^a	3.31	25.5
OBC	300	8.62±0.22^b			70	3.76±0.35^c		
CBC		9.20±0.43^b				3.22±0.23^b		
OBC	450	13.39±0.57^c	2.40	8.40	80	4.36±0.37^d	3.41	19.72
CBC		14.80±0.95^d				4.24±0.42^d		

Different letters in the same column indicate that the difference between the means is significant (p<0.05). (OBC: Organic; CBC: Conventional)

The samples dried with IMW have higher D_{eff}, lower the pre-exponential factor of the Arrhenius equation (D_0) and E_a values. High MW powers accelerate the water molecules and evaporate faster by increasing the vapor pressure in the product, thus providing a faster reduction in moisture content corresponding to higher D_{eff} values (Thuwapanichayanan, et al., 2011; Darvishi, et al., 2013; Soysal et al., 2009). The D_{eff} values determined were different from 10^{-11} to 10^{-9} m^2s^{-1} compared to the black carrot materials used in other studies (Haq et al., 2018; Talih et al., 2017). The D_{eff} values of the samples dried at 80°C and 150 W are close to each other (for OBC and CBC, respectively 80°C:4.36 and 4.24 m^2s^{-1}; 150 W: 4.29 and 4.50 m^2s^{-1}).

The E_a values determine the sensitivity of the diffusivity to temperature. Higher E_a also indicates that the reaction rate is more sensitive to changes in temperature (Turhan et al., 1997; Ma et al., 2017). Low E_a values produce a fast reaction, while high E_a values produce a slow reaction (Ma et al., 2017). The E_a values obtained from the slope of the lines as a result of the comparison of the ln(D_{eff}) value and the m/P_a value for IMW were calculated as 8.41x10^{-3} and 8.40x10^{-3} W g^{-1} for OBC and CBC samples, respectively. This result shows that the growing conditions of OBC or CBC dried by IMW did not significantly change the structural properties. OBC and CBC samples demonstrated the same resistance to moisture carried over from the drying material as a result of IMW. There are similar studies on the lack of a significant difference in E_a values for organic and conventional samples obtained in the current study (Arslan et al., 2020b).

The E_a values of OBC and CBC samples dried by HA were found as 25.50 and 19.72 kJ mol^{-1}, respectively. The E_a values for OBC and CBC samples dried by HA have a significant difference. Growing conditions of OBC and CBC samples dried with HA significantly was affected the structural properties.

The rate of a chemical reaction generally increases with increasing temperature values (Ma et al., 2017). As the reaction temperature increases, collisions become more frequent as a result of the increase in the average molecular kinetic energy and the increase in the number of molecules with kinetic energy exceeding the E_a (Ma et al., 2017). The E_a values obtained for the samples dried with the IMW were resulted lower values than the HA. This may cause of removing moisture from the product as a result of the working principle of the drying methods.

4. Conclusions

This study was carried out to organic and same variety of conventional black carrots dried by using IMW and HA method and to evaluate the effects of applied power and temperature levels on color and quality properties and to model the drying kinetics data mathematically. The samples dried with IMW had higher D_{eff} (4.29-14.80x$10^{-9}$$m^2s^{-1}$) and values compared to HA (2.59-4.24x10^{-9} m^2s^{-1}). L* and ΔE values of the final products increased significantly by increasing the power/temperature levels applied during drying and the powder samples were lighter in color compared to the fresh samples.

The total phenolic (OBC: 903.3 mg/100g GAE; CBC: 865.8 mg/100g GAE) and total antioxidant capacity (OBC: 427.4 µmol Trolox/100 g; CBC: 269.9 µmol Trolox/100 g according to DPPH method) values were higher in fresh OBC samples compared to the conventional variety. These results demonstrated that OBC is superior to the CBC in terms of higher total phenolic and total antioxidant content. The total phenolic components, which are sensitive to heat, were not decrease or increase in parallel with the temperature/power levels applied with the drying methods so it can say that the phenolic components are affected differently depending on the product type, the food structure and composition. As a result, it was determined that the temperature/power levels applied to the products during the drying process, thus the drying times and the methods of removing moisture from the product are effective in the preservation of the total phenolic components. For this reason, it is important to use appropriate temperature and power levels for the protection, increase and sustainability of phenolic compounds in terms of nutritiveness of the products. The total phenolic and total antioxidant capacity values were better preserved with the IMW method, which requires low E_a. Evaluation of other organic samples in terms of drying parameters compared to conventional will shed light on future studies.

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