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ORIGINAL ARTICLE

Quality retention in pumpkin powder dried by combined microwave-convective drying

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Abstract Three distinct drying methods, microwave drying (MWD), convective drying (CVD) and microwave-convective drying (MWCVD) with a grinding process were applied to obtain pumpkin powder. The effects of CVD (60, 70 & 80 °C), MWD (100 & 200 W) and MWCVD (100 W-60 °C, 100 W-70 °C, 100 W-80 °C, 200 W-60 °C, 200 W-70 °C, and 200 W-80 °C) applications on the physicochemical properties (water activity, bulk, tapped & particle densities, porosity, flowability, cohesiveness, swelling capacity, water holding capacity and water solubility index), color values (L^*, a^*, b^*, C, α^o and Δe), bioactive compounds (5-Hydroxymethyl-2-furfural (HMF), total phenolic content (TPC) and antioxidant capacity (DPPH and ABTS)) of the eleven pumpkin fruit powders were compared. The MWCVD, namely pumpkin powders dried at 200 W–80 °C resulted in shorter drying times with high-quality dried pumpkin powders. The bulk, tapped and particle densities of pumpkin powders at 200 W-80 °C by MWCVD were 0.56, 0.66 and 1.74 g/cm^3, respectively. These values are indicators of the good porosity (61.82%) of pumpkin powders. In addition, the highest TPC (1277.08 mg GA/100 g dw) and ABTS (126.99 ± 3.31 μmol Trolox/g dw) was observed for microwave-convective dried pumpkin powders at 200 W-80 °C. On the other hand, the lowest HMF level (10.12 ± 1.78 mg/kg dw) was found for the pumpkin poowders dried by MWCVD at 200 W-80 °C. In overall, dried pumpkin powders by a MWCVD method can be employed to acquire a high-quality food material along with an enhanced physicochemical properties, color and bioactive components.

Keywords Pumpkin · Bioactive compounds · Fruit powder · Microwave-convective drying · Physicochemical properties

Abbreviations

MWD	Microwave drying
CVD	Convective drying
MWCVD	Microwave-convective drying
HMF	5-Hydroxymethyl-2-furfural
TPC	Total phenolic content

Introduction

The pumpkin is a squash fruit, generally orange in color when ripe. The value of the fruit is raised when cooked and pureed. The pumpkin fruit is used in several dishes such as soups and breads. It was observed that the chemical content of fresh pumpkin was 80–96% moisture, 4.6–6.5% sugars, 0.6–1.8% proteins, 0.0–0.2% lipid & 0.5–1.3% fiber (Fennema et al 2004). These values linked with its antioxidant capacity allow the pumpkin fruits to have a significant health-promoting impact. The yellow to orange color of the pumpkin fruit drives from these bioactive components. The good performance of the pumpkin-fiber materials displays the possibility of their usage as a food product (Escalada et al 2007).

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An alternative to fresh produces is their dried form, which enables their usage for the off-season. But, the drying application might have a powerful effect on the dried product quality because of the process includes simultaneous coupled heat and mass transfer developments which takes place in dried or dehydrated food materials (Guiné and Barroca 2012). Currently, several approaches in order to preserve food and foodstuffs have been come into the consideration especially in relation to the advancing technology and nutritional styles. Practical and easy-to-perform applications such as the microwave drying method, which stands out among these methods, are preferred by people and applied widely. The method of drying food with microwave leads to much faster moisture transfer compared to traditional drying methods, in addition to the nutritional values of food materials are maintained better with a microwave drying (Yildiz and Izli 2019). On the other hand, it's known that not all foodstuffs are suitable for microwave drying, and the wavelength and frequency value to be used in determining the final product quality are of great importance. Another of the most popular methods of drying food is the convective drying method due to its low costs and large capacities. However, this method causes deterioration in taste, color and nutrient compounds in the products due to the high temperatures. Combining microwave and convective drying methods is a promising method that reduce the negative aspects of the two methods and increase the product quality and energy efficiency (Yildiz and Izli 2020).

Pumpkin fruits are very sensitive to microbial spoilage and requires alternative preservation methods to increase their shelf life, such as drying (Monteiro 2018). It is possible to use powders of dried pumpkins to prepare instant soups, breads, and cakes. The microstructure and physicochemical characteristics of the final product can be changed based on drying methods (Seremet et al 2016). There are several studies on producing dried pumpkin, including air-drying (Guiné and Barroca 2012), microwave drying (Nawirska-Olszańska et al 2017), microwave combined with hot air drying (Seremet et al 2016). There is not any reports for the comparison or efficiency of MWCVD on pumpkin fruit powders in comparison with MWD and/or CVD alone treatment. The goal of the current work was to explore the optimum drying variables (temperature and power) for pumpkin fruit based on dried powder quality. The important physicochemical properties, colour values (L^*, a^*, b^*, C, α^o and Δe) and bioactive compounds of pumpkin powders obtained by MWCVD were explored and compared with the outcomes of MW and CV alone dried pumpkin powders.

Materials and methods

Sample preparation

Fresh pumpkin fruits were obtained from a farmer's supermarket in Bursa, Turkey and kept at 4 ± 0.5 °C till drying experiments. Moisture level of fresh pumpkin fruit at first was confirmed to be 85.66 ± 1.55% with oven drying method (Memmert UN55, Germany) at 105 ± 5 °C (Yildiz and Izli 2019). The samples were cut into slices that have a thickness of 1.8 ± 0.03 mm and a side length of 18 ± 0.15 mm with the help of a food slicer (Nice Dicer, China).

Drying procedure

The drying operation was applied by using a laboratory type microwave-convective oven of 230 V, 50 Hz and 2465 MHz frequency (Arçelik KMF 833I, Turkey). Three distinct drying methods were applied throughout the drying experiments, which are namely microwave (MW) convective (CV) and microwave-convective (MWCV) drying. The setup runs in the convective mode with 50, 60 and 70 °C drying temperatures. At microwave-drying mode, output power levels were determined as 100 W and 200 W, and at microwave-convective drying mode, six discrete power level-temperature combinations (100 W-50 °C, 100 W-60 °C, 100 W-70 °C, 200 W-50 °C, 200 W-60 °C and 200 W-70 °C) were carried out. Dried pumpkin slices were grinded (Sinbo SCM 2934, Turkey) and passed through a 60-mesh screen to obtain pumpkin powders.

Chemical and Physicochemical properties

Proximate analysis

The chemical characteristics (moisture, ash, protein, lipid, both total & reducing sugars) of the fresh pumpkin samples were determined based on the method proposed by Cemeroğlu (2010). The dry matter of pumpkin slices was analyzed via drying (Memmert UN55, Germany) at 105 ± 5 °C till the samples arrived at a constant weight. Ash content of fresh pumpkin was determined in a muffle furnace (Protherm PLF 110/8, Turkey) at 550 °C to a white color. Protein content was measured by the Kjeldahl approach and determined based on the conversion factor of 6.25 (Buchi K-355, Switzerland). Lipid content of fresh pumpkins was determined by a n-hexane with a Soxhlet extractor (Buchi E-816, Switzerland). Both total and reducing sugar contents of pumpkin samples were measured based on the Lane-Eynon method (Yıldız et al 2015).

Water activity (a_w)

The a_w levels of pumpkin powders were determined by the aid of a water activity meter (Nova Lab master, Switzerland).

Bulk and tapped densities

The bulk density (ρ_{bulk}, g/cm^3) was measured by gently placing the powders into a 10 mL graduated cylinder. The rate of mass to volume obtained from the cylinder was expressed as the bulk density. The same cylinder was tapped 125 times for the measurement of the tapped density (ρ_{tapped}, g/cm^3) (Michalska et al 2016).

Particle density

The particle density ($\rho_{particle}$, g/cm^3) of pumpkin powders were calculated according to A/S Niro Atomizer (1978) with some modifications. One g of each of the dried pumpkin powders was placed in a 10 mL graduated cylinder with a glass stopper. And then 5 mL of petroleum ether was added and the cylinder was shaken until all the powder particulates were suspended. Finally, all the powder particulates on the cylinder wall were rinsed down with a further 1 mL of petroleum ether (6 mL in total) and total volume of petroleum ether with suspended powder was read. The particle density was calculated according to the Eq. 1:

$$\rho_{\text{particle}} = \frac{\text{Mass of the powder (g)}}{\text{total volume of petroleum ether with suspended powder (mL) - 6}} \tag{1}$$

Porosity

Porosity (ε) of the pumpkin powders was measured according to the connection between the particle (ρ_{particle}) and tapped (ρ_{tapped}) densities of the pumpkin powders as displayed in Eq. 2 (Michalska et al 2016):

$$\varepsilon = \frac{\left(\rho_{\text{particle}} - \rho_{\text{tapped}}\right)}{\rho_{\text{particle}}} \times 100 \tag{2}$$

Flowability and cohesiveness

The Carr index (*CI*) (Carr 1965) and Hausner ratio (*HR*) (Hausner 1967) were used in order to determine the flowability and cohesiveness values of the pumpkin powders, subsequently. Both *CI* and *HR* were determined by the ρ_{tapped} and ρ_{bulk} of the pumpkin powders as followings (Eqs. 3 & 4):

$$CI = \frac{\rho_{tapped} - \rho_{bulk}}{\rho_{tapped}} \times 100 \tag{3}$$

$$HR = \frac{\rho_{tapped}}{\rho_{bulk}} \tag{4}$$

Swelling capacity

One g of the pumpkin powder (M) was placed into a graduated cylinder, and the volume (V1) was reported. After that, 10 mL of distilled water (DW) was put and the cylinder shaken in order to obtain well-mixed solution. The pumpkin powders then were let to expand as far as possible over twenty-four hours at room temperature and then the volumes of the wet pumpkin powders (V2) were reported (Lecumberri et al 2007). The swelling capacity was calculated as follows:

$$Swelling\,capacity\,(mL/g) = (\mathrm{V2} - \mathrm{V1})/M \tag{5}$$

Water holding capacity (WHC)

Two g of each of the dried pumpkin powders (M1) was put into a pre-weighed centrifuge tube (M). Then, DW and pumpkin powders were combined and the centrifuge tube shaken for the well-mixed solution. The rate of powder to water was determined as 0.05:1 (m/v). The mix was placed in a water bath (Memmert WNB 14, Germany) at 60 °C for a half an hour. It was put in an ice bath for instant cooling for a half an hour and then centrifuged (Hettich Universal 320 R, Germany) for 20 min at 3500 rpm. The supernatant was ignored and the remaining components were weighed (M2) (Anderson 1982). The WHC was determined based on the Eq. 6:

$$Water\,holding\,capacity\,(g/g) = (\mathrm{M2} - \mathrm{M})/\mathrm{M1} \tag{6}$$

Water solubility index (WSI)

The pumpkin powders were weighed as 0.80 g (S1) and put into a centrifuge tube. Then DW was combined with these powder particles and mixed completely. The rate of pumpkin powders to water was arranged as 0.02:1 (m/v). The mixed solution was placed in a water bath at 80 °C for a half an hour (Memmert WNB 14, Germany) then centrifuged for 20 min at 3500 rpm (Hettich Universal 320 R, Germany). Following the centrifugation process, the supernatant was placed into a pre-weighed (S) evaporating dish and dried at 105 ± 5 °C (Memmert UN55, Germany). The dried pumpkin powders and evaporating dish were weighed (S2) **(**Zhang et al 2012**)**. The WSI was calculated according to the Eq. 7:

$$\text{Water solubility index}\,(\%) = (\mathrm{S2} - \mathrm{S})/\mathrm{S1} \times 100 \qquad (7)$$

Color analysis

With the use of a colorimeter (PCE-CSM 3, USA), classification of *L** values (represents lightness), *a** values (represents redness/greenness value) and *b** values (represents yellowness/blueness value) of both fresh and dried pumpkin powders were realized by means of 10 distinct readings at random positions on the pumpkin fruit surface. Furthermore, the Chroma (*C*), hue angle (α) and total color differences (*ΔE*) were gauged as below:

$$C = \sqrt{(a^2 + b^2)} \qquad (8)$$

$$\alpha = \tan^{-1}\left(\frac{b}{a}\right) \qquad (9)$$

$$\Delta E = \sqrt{(L* - L0*)^2 + (a* - a0*)^2 + (b* - b0*)^2} \qquad (10)$$

where subscript ''o'' denotes the color of fresh pumpkin sample.

Bioactive compounds

5-Hydroxymethyl-2-furfural (HMF) analysis

Five hundred mg of pumpkin powders were triple extracted by 10 mL of distilled water (5, 2.5 and 2.5 mL, respectively), and shaken for 10 min in each step. Supernatants were transferred to a test tube and the tube was centrifuged at 3500 rpm for 3 min (Hettich Universal 320 R, Germany) to obtain a clear extract. The combined extract was precipitated by Carez clarification. Then the mix was filtered through 0.45 µm nylon filter and transferred into a vial. 10 µL of the filtered extract was injected into Agilent 1260 HPLC setup (German) coupled with a diode aray detector (DAD), a quarternary pump, a temperature-controlled oven, and an autosampler. Separation was managed on a Zorbax ODS dC18 column (150 mm × 4.6 mm, 5 µm) at 30 °C and isocratic mix of 1% acetic acid (AA) in water and methanol (70:30, v/v) was used as the mobile phase at a flow ratio of 0.6 mL/min. The detection was performed at 280 nm. The quantification of HMF levels was figured out rely on the external calibration curve ranged from 0.5 to 10 µg/mL and the findings were presented as mg/ kg on dry weight (d.w).

Pumpkin extract preparation

Five hundred mg of fresh and dried pumpkin powders were weighed in a test tube and extracted 3 times with 10 mL of methanol: water (80:20, v/v) and shaken for 10 min in each and every step. Later then, the tube was centrifuged at 3500 rpm for 3 min (Hettich Universal 320 R, Germany) to obtain a clear extract and it was combined in another tube. The analysis of TPC & AT capacity was carried out by using the pumpkin extracts.

Total phenolic content (TPC)

The TPC of pumpkin powders which is in agreement with the approach stated by Singleton et al (1999) was determined with slight alterations. In brief, a part of extract was filtered through 0.45 µm nylon filter and 1.6 mL of Folin-Ciocalte's reagent was mixed into 0.4 mL of filtered extract accordingly diluted by methanol: water (80:20, v/v) in a test tube. Contents were mixed by vortexing and left to sit for 5 min. Following that, 1.6 mL of 20% Na_2CO_3 was put into the mixture and vortexed, the tubes were let to stay at ambient temperature for 90 min. Subsequently, the mixture was centrifugated at 3500 rpm for 3 min (Hettich Universal 320 R, Germany) and transferred into a cuvette. The analysis was carried out by a **UV–VIS spectrophotometer** (Mecasys Optizen Pop, Korean) at 765 nm and quantification was figured out by a gallic acid calibration curve, built range from 0 to 30 µg/mL. The findings were demonstrated as mg GAE/100 g of dry weight.

Antioxidant capacity (ATC)

DPPH method ATC of pumpkin powders was measured based on the DPPH method (Brand-Williams et al 1995) with small changes. Stock solution of DPPH was arranged via dissolving 10 mg of DPPH in 25 mL of ethanol and diluted with 25 mL of distilled water. Then, the working solution of DPPH was arranged by roundly 400 mL of water: ethanol (1:1, v/v) having absorbance values around 0.75–0.80 at 525 nm. A 0.2 mL of pumpkin extract was put in a tube and mixed by 3.8 mL of DPPH solution. The tube was put into an orbital shaker and it was mixed for 26 min at 350 rpm in darkness at room temperature. Following centrifugation at 3500 rpm for 3 min (Hettich Universal 320 R, Germany), the optically clear supernatant was obtained, and the absorbance was evaluated at 525 nm using a Mecasys model Optizen POP variable wavelength UV–VIS spectrophotometer (Korean). All measurements were performed at 30 min after reacting with extract and DPPH solution. The ATC was demonstrated as µmol of Trolox equivalent (TE) per 1 g d.w. of pumpkin powder.

ABTS method ABTS radical solution was prepared with respect to the procedure proposed previously (Serpen et al 2012) with slight changes. ABTS was dissolved in water to a 7 mmol/L aqueous dispersion and stock solution of ABTS was arranged via reacting 7 mM liquid dispersion of

ABTS with 2.45 mM potassium persulfate. The mixed solution was stayed in a dark room temperature for 12–16 h until the analysis (Re et al 1999). Then, the absorbance of ABTS solution was adjusted to a level between 0.75–0.8 at 734 nm by diluting the blend of water: ethanol (50:50, v/v). A 0.2 mL of diluted pumpkin extract was put in a tube and well—mixed with 3.5 mL of ABTS solution. The tube was put into an orbital shaker and it was mixed for 26 min at 350 rpm in darkness at room temperature. Following centrifugation at 3500 rpm for 3 min (Hettich Universal 320 R, Germany), the optically clear supernatant was obtained, and the absorbance measurement was carried out at 734 nm by the aid of a Mecasys model Optizen POP variable wavelength UV–VIS spectrophotometer (Korean). All measurement was performed at 30 min after reacting with extract and ABTS solution. The ATC of pumpkin powders was expressed as µmol of Trolox equivalent (TE) per 1 g d.w. of pumpkin powder.

Statistical analysis

Determination of the analyzed variables was carried out in three replications. The findings were analysed by JMP (Version 7.0, SAS Institute Inc., Carry, NC, USA). Mean differences were analyzed for significance with aleast significant difference (LSD) test at a 5% value of significances.

Results and discussion

Chemical and physicochemical properties

The chemical characteristics (moisture, ash, protein, lipid, total sugar and reducing sugar) of the fresh pumpkin samples were provided in Table 1. The physicochemical properties of dried-pumpkin powders, namely water activity, bulk, tapped & particle densities, porosity, flowability (carr index) and cohesiveness (hausner ratio), swelling capacity, water holding capacity and water solubility index with different drying methods are given in Tables 2 and 3. The chemical composition of fresh pumpkin was found with 85.66% moisture content, 1.06% ash, 0.97% proteins, 0.22% lipids, 4.42% total sugars and 1.66% reducing sugars.

Table 1 Chemical properties of the fresh pumpkin fruit

Parameters	(%)
Moisture	85.66 ± 1.55
Ash	1.06 ± 0.04
Protein	0.97 ± 0.19
Lipid	0.22 ± 0.04
Total sugar	4.42 ± 0.21
Reducing sugar	1.66 ± 0.02

a_w is the availability of free water in a food products in charge of any biochemical and/or microbiological developments. High a_w expresses more free water accessible for biochemical and microbiological developments which is the reason of shorter shelf life. The combined microwave-convective dried pumpkin powders showed the lowest a_w content of 0.19 at 200 W- 80 °C and the highest a_w level of 0.28 at 60 °C as determined by CVD. All the pumpkin powders demonstrated a_w contents under 0.3 (Table 2), which is an indicator of good powder stability. They could be thought biochemically and/or microbiologically well-stable. In comprehensively, food powders which have a a_w of 0.6 or lower is usually recognized to be as safe from microbiological or biochemical reactions (Kowalski and Szadzińska, 2014). While the a_w was determined as 0.28 at 60 °C, it was decreased and determined as 0.21 and 0.23 at 70 °C and 80 °C, respectively. Similar findings were found by De Medeiros et al (2014) who stated the a_w in yoghurt powders by different drying temperatures including 130, 150 and 170 °C. The a_w of dried pumpkin powder was remarkably influenced by the microwave power as well as drying temperature (Table 2). The a_w decreased with an increase in power during microwave drying. While the water activity was found as 0.24 at 100 W, it was decreased and determined as 0.22 at 200 W.

Pumpkin powders created at different air temperatures and powers exhibited a significant change ($p \leq 0.05$) in bulk density (Table 2). The highest bulk density was determined by MWCVD at 200 W-80 °C (0.56 g/cm^3), whereas the lowest bulk density was presented in pumkin powders dried by CVD at 70 °C (0.33 g/cm^3). The decline in bulk density with increased temperature might be because of faster evaporation ratio with more porous and fragmented form of the food material. Furthermore, at higher air temperature, the glassy structure of food powders hinders the free flowing nature and develops more porous powders. The bulk characteristics especially ρ_{tapped} and ρ_{bulk} of a product powder are more related to particle size of the food product and its distribution. Lower ρ_{bulk} of a food material is not a preferable property causing in a greater packaging volume. In addition, lower the bulk density, more occluded air within the food powders would be and a greater possibility for the food oxidation resulted with reduced storage stability. With regard to tapped density, pumpkin powders presented a significant difference ($p \leq 0.05$) among the specimens by various drying applications (Table 2). The highest tapped density similar to the bulk density was shown by MWCVD at 200 W- 80 °C (0.66 g/cm^3), whereas the lowest tapped density was demonstrated by convective dried pumpkin powders at 70 °C (0.42 g/cm^3). Tapped density is a significant

Table 2 Physicochemical properties of the dried pumpkin powders

Drying method	Water activity	Bulk density (g/cm^{3})	Tapped density (g/cm^{3})	Particle density (g/cm^{3})	Porosity	Carr index (%)	Hausner ratio
Fresh	0.96 ± 0.00^{a}						
CVD							
60 °C	0.28 ± 0.02	0.36 ± 0.01^{f}	0.55 ± 0.02^{ef}	1.97 ± 0.06^{bc}	72.14 ± 1.74^{a}	35.10 ± 0.87^{a}	1.54 ± 0.02^{a}
70 °C	0.21 ± 0.01^{h}	0.33 ± 0.01^{g}	0.42 ± 0.00^{g}	1.50 ± 0.07^{e}	71.84 ± 1.44^{ab}	22.12 ± 0.65^{d}	1.28 ± 0.01^{d}
80 °C	0.23 ± 0.01^{f}	0.47 ± 0.03	0.53 ± 0.01^{f}	1.55 ± 0.01^{e}	65.49 ± 0.33^{d}	21.77 ± 0.20d	1.18 ± 0.00^{ef}
MWD							
100 W	0.24 ± 0.01^{ef}	0.42 ± 0.02^{de}	0.54 ± 0.03^{f}	1.75 ± 0.06^{d}	69.26 ± 0.59^{b}	21.07 ± 0.94^{d}	1.27 ± 0.02^{d}
200 W	0.22 ± 0.01^{g}	0.43 ± 0.01^{d}	0.56 ± 0.01^{def}	1.55 ± 0.08^{e}	63.57 ± 1.22^{de}	23.66 ± 0.36^{cd}	1.31 ± 0.03^{d}
MWCVD							
100 W-60°C	0.25 ± 0.01^{d}	0.37 ± 0.00^{f}	0.53 ± 0.00^{f}	2.05 ± 0.06^{ab}	74.20 ± 0.56^{a}	30.27 ± 0.90^{b}	1.43 ± 0.02^{b}
100 W-70°C	0.26 ± 0.03	0.40 ± 0.02^{e}	0.58 ± 0.02^{cde}	2.09 ± 0.03^{a}	72.36 ± 1.17^{a}	29.97 ± 1.13^{b}	1.43 ± 0.02^{b}
100 W-80°C	0.20 ± 0.01^{i}	0.46 ± 0.00^{c}	0.60 ± 0.03^{bc}	1.55 ± 0.04^{e}	60.97 ± 1.24^{e}	23.02 ± 3.63^{cd}	1.30 ± 0.06^{cd}
200 W-60°C	0.24 ± 0.01^{de}	0.48 ± 0.00^{c}	0.64 ± 0.01^{ab}	1.90 ± 0.04^{c}	66.25 ± 1.24^{c}	25.89 ± 0.43^{c}	1.35 ± 0.03
200 W-70°C	0.26 ± 0.00^{c}	0.50 ± 0.02	0.59 ± 0.00^{cd}	1.57 ± 0.03^{e}	62.19 ± 0.95^{e}	16.04 ± 1.47^{e}	1.19 ± 0.02^{e}
200 W-80°C	0.19 ± 0.01^{j}	0.56 ± 0.00^{a}	0.66 ± 0.02^{a}	1.74 ± 0.04^{d}	61.82 ± 1.86^{e}	15.28 ± 1.96^{e}	1.13 ± 0.03^{f}

$^{a-j}$Means superscript with different alphabets in the same column differ significantly ($p \leq 0.05$)

Table 3 Physicochemical properties of the dried pumpkin powders

Drying method	Swelling capacity (mL/g)	Water holding capacity (g/g)	Water solubility index (%)
CVD			
60 °C	11.20 ± 0.00^{c}	7.57 ± 0.16^{b}	37.32 ± 0.34^{d}
70 °C	10.60 ± 0.00^{cd}	7.06 ± 0.07^{bc}	37.36 ± 0.42^{d}
80 °C	9.64 ± 0.36^{ef}	6.48 ± 0.20^{d}	39.08 ± 0.46^{c}
MWD			
100 W	9.87 ± 0.11d^{ef}	4.92 ± 0.32^{f}	39.98 ± 0.44^{b}
200 W	10.65 ± 0.17^{cd}	5.96 ± 0.19^{e}	29.68 ± 0.27^{g}
MWCVD			
100 W-60°C	10.58 ± 0.86^{cd}	7.49 ± 0.70^{bc}	37.87 ± 0.15^{d}
100 W-70°C	10.55 ± 0.29^{cd}	6.98 ± 0.26^{cd}	37.57 ± 0.41^{d}
100 W-80°C	10.17 ± 0.31^{de}	4.82 ± 0.07^{fg}	45.06 ± 1.09^{a}
200 W-60°C	18.05 ± 0.69^{a}	9.20 ± 0.25^{a}	30.97 ± 0.55^{f}
200 W-70°C	16.56 ± 0.04^{b}	8.93 ± 0.19^{a}	32.45 ± 0.20^{e}
200 W-80°C	9.28 ± 0.16^{f}	4.32 ± 0.38^{g}	26.19 ± 0.44^{h}

$^{a-h}$Means superscript with different alphabets in the same column differ significantly ($p \leq 0.05$)

indicator linked with packaging, transportation, and commercialization of food powders, therefore, this factor could be beneficial in terms of weight and amount of food materials which would fit into a container. Dried food products which have a high density could be kept in smaller containers compared to low density food materials. While the tapped density was found as 0.55 g/cm^{3} at 60 °C, it was decreased and determined as 0.42 and 0.53 g/cm^{3} at 70 °C and 80 °C, subsequently. Similarly, while the particle density was found as 1.97 g/cm^{3} at 60 °C, it was decreased and determined as 1.50 and 1.55 g/cm^{3} at 70 °C and 80 °C, respectively (Table 2). The lowest particle density was determined by the rise in drying air temperature. ρ_{bulk} and $\rho_{particle}$ are valuable low-cost parameters in order to anticipate the quality of particulates.

Porosity is described as the void fraction in the food product powders. It is a significant feature which plays remarkable role during reconstitution of product powders. The porosity values displayed a significant change ($p \leq 0.05$) among the pumpkin powders, ranging between 61.82 and 72.36% (Table 2). The lowest porosity was obtained for the powders dried by MWCVD at 200 W-80 °C (61.82%, Table 2). MWC and CVD pumpkin powders showed significantly higher porosity compared to the powders obtained by MWCVD. The higher levels of porosity show the existence of a larger spaces among the particulates, containing O_2 available for degradation developments. The temperature and power levels had remarkable impact on the porosity levels of pumpkin powders. Rising the drying air temperatures caused lower porosity values (Table 2). While the porosity value was found as 72.14% at 60 °C, it was decreased and determined as 65.49% at 80 °C. Similarly, increasing the power levels of microwave led to lower porosity. While the porosity value was found as 69.26% at 100 W, it was decreased and determined as 63.57% at 200 W. The low content of porosity shows lower space among the particulates, thus, low O_2 content accessible for degradation phenomena (Ferrari et al 2012). The porosity is related to bulk density indirectly which shows that the incorporation of air into the foam caused accumulation of air within the dried particulates, causing more porous and less dense structure (Franco et al 2016) which is also observed in the current work. MWCV dried pumpkin powders at 200 W- 80 °C showed the highest bulk density (0.56 g/cm^3) and lowest porosity (61.82%). In general, food powders with higher ρ_{bulk} and lower porosity are preferred for the increment in their storage stability.

Table 2 shows the impacts of drying parameters on flowability and cohesiveness of pumpkin powders. Flowability is a crucial feature for dried fruit and/or vegetable particulates and was demonstrated as the Carr index (*CI*). The higher value of the *CI* is the indicator of poor flowability. The Carr index was changed from 15.28 to 35.10% for the pumpkin powders (Table 2). While the highest value of CI was shown by pumpkin powders at 60 °C by CVD (35.10%), the lowest CI was shown by MWCVD pumpkin powders at 200 W-80°C (15.28%). Hausner ratio (HR) values representing cohesiveness of the food product changed between 1.13 and 1.54% (Table 2). The highest value of cohesiveness was shown by pumpkin powders at 60 °C by CVD (1.54%), while the lowest was shown by MWCVD pumpkin powders at 200 W-80°C (1.13%). According to the classification given by Abdullah and Geldart (1999), powders of hasuner ratio under 1.25 were described as lowly cohesive. Szulc and Lenart (2012) figured out that the *HR* of whole milk, rice gruel, granulated sugars and berry fruit powders were 1.29, 1.12, 1.36 and 1.15, subsequently. In addition, various amounts of the specific powders were used for the production of baby powder and the *HR* of baby powders changed between 1.10 and 1.28 at several processing conditions. CV and MW-dried pumpkin powders exhibited a significantly higher Hausner ratio and Carr Index levels compared to the pumpkin powders by MWCVD (Table 2). The reason for this possible flowability could be because of higher a_w, which leads to particulates to stick tightly and increase the resistance against to flowness. For dried powder samples, effective forces such as van der Waals, electrostatic, and magnetic forces have an remarkable role for the development of resistance against to flowing (Fitzpatrick 2013). Smaller particulate size leads to higher contact surface area per unit mass of food powder which raises the effect of van der Waals forces. Another significant factor that has an important impact on the flowability behavior of food powders is recognized as water content. Above a specific point, liquid bridges would be created among the particulates causing the form capillary forces at the contact points of particulates. Capillary forces constrict to particle movements via binding them (Fitzpatrick 2013). By taking into account of *CI* and *HR* values, excellent flowability (15.28%), and low cohesiveness (1.13) were determined for MWCV-dried pumpkin powders at 200 W-80°C. Based on the findings we might list pumpkin powders obtained by MWCVD at 200 W-80°C as an excellent and good flowability pumpkin powders.

Water solubility index (WSI) is the reconstitution feature which is calculated to figure out the impact of process determinants. The impact of various drying conditions on pumpkin powder solubility is presented in Table 3. The solubility indexes of pumpkin powders changed from 26.19% to 45.06% (Table 3). Increasing drying temperature during convective drying had a significant effect on powder solubility. At the highest temperature (80 °C), pumpkin powders exhibited the highest solubility (39.08%), whereas at the lowest temperature (60 °C), pumpkin powders presented the lowest solubility (37.32%). The findings showed that the water solubility of pumpkin powders raised by higher drying air temperatures. On the other hand, our findings certainly demonstrated that the water holding capacity decreased with increased drying temperatures. At the highest temperature (80 °C), pumpkin powders displayed the lowest holding capacity (6.48 g/g), whereas at the lowest temperature (60 °C), pumpkin powders exhibited the highest holding capacity (7.57 g/g). Among all drying methods, the lowest water holding capacity was observed for the pumpkin powders dried by MWCVD at 200 W-80 °C. The content of non-soluble component development in food materials is connected with the drying temperature before and at the time of drying procedure. Drying of sugar rich material remarkably effects the water solubility of food product powder because of the structural change of sugar from crystalline to amorphous state. Water holding and swelling were confirmed as 2 important functions of fruit powders. There is a positive relationship between the swelling and water holding capacities of pumpkin powders (Table 3). While the lowest swelling capacity (9.28 mL/g) and water holding capacity (4.32 g/g) were observed for the dried pumpkin powders at 200 W-80 °C by microwave-convective drying, the highest swelling capacity (18.05 mL/g) and water holding capacity (9.20 g/g) were observed for the dried pumpkin powders at 200 W-60 °C by microwave-convective drying. The prompt feature of a powder is described as the ability of a powder to dissolve in water. Therefore, the ideal fruit and/or vegetable powder would wet quickly and efficiently, sink rather than float and disperse/dissolve with no lumps. In the case of dried-powdered food materials, various features effect the overall reconstitution properties. As an example, solubility is the last step of powder dissolution and is thought as an important factor for the whole reconstitution quality of food materials. Commercial milk powder producers generally use this feature as a criteria in order to show the milk powder quality. Usually, dispersibility and wettability based on particle size, density, porosity, surface charge, surface area, and the existence of amphipathic compounds and the surface activity of the particulates (Kim et al 2002). The lower wettability which is demonstrated by less dissolution values could be depend on the lower solubility of the denatured proteins.

Color measurement

The colour parameters of fresh and dried pumpkin fruit powders are tabulated in Table 4. While the lightness value of fresh pumpkins was found as 70.43, it was changed from 61.15 to 68.87 in dried pumpkin powders. Dried pumpkin powders at 200 W-80 °C showed significantly higher lightness values compared to the other dried pumpkin powders (Table 4). On the other hand, the lowest lightness values were detected in convective-dried samples at 60 °C compared to the other dried pumpkin powders. The lower lightness meaning darker display of the convective-dried pumpkin powders in comparison with other dried samples could be for the reason of the non-enzymatic browning (Yildiz and Izli 2019). Color changes that occur as a result of drying pumpkin samples is thought to be caused by degradation of pigments by heat treatment and enzymatic or non-enzymatic (Maillard) browning reactions (Yildiz and Izli 2019). The a^* values of the dried pumpkin powders were significantly ($p \leq 0.05$) increased compared to fresh sample. Vadivambal and Jayasa (2007) stated that drying process led to a rise in $a*$ value which is the indication of browning development. It has been announced that the browning value increases with higher temperature in goldenberry fruits dried with two different microwave-hot air combination methods (İzli et al 2014). It was reported that in the hot air drying study performed by Sacilik and Elicin (2006) the browning values increased on the products that they've dried with increasing temperatures. Orsat et al (2005) found that as the MW power levels they applied in their drying studies with the microwave drying method increased, the browning values on the products they've dried increased. Moreover, studies have reported that longer drying times and high temperatures cause more pigments to deteriorate and the colors of foods to change more. In this study, it was also observed that the microwave-dried (100 W) and convective-dried (60 °C) pumpkin samples which exposed to drying application for the longest time (196 min and 162 min, respectively) showed the most color changes. All in all, the pumpkin powders dried with microwave-convective drying at 200 W–80 °C showed the closest a^* value to the fresh pumpkin fruit (Table 4). In addition, the closest b^* value to the fresh pumpkin was also observed for the pumpkin powders dried by microwave-convective drying at 200 W–80 °C. The *C* parameter which is the indication of color intensity of pumpkin powders presented significantly higher levels in comparison with the fresh pumkin slices. While the highest *C* value was determined for the pumpkin powders by microwave-convective drying at 200 W–80 °C, the lowest *C* value was found for the fresh pumpkin slices (Table 4). The total colour change (Δe) which is about the differences in L_*, a_*, *and* b_* values was also analyzed (Table 4). Δe value of pumpkin powders by MWCVD at 200 W–80 °C presented the lowest value in comparison with the other drying conditions. In shortly, the closest values to the fresh pumpkin samples for all colour parameters (lightness, redness and yellowness) were determined for microwave-convective dried pumpkin powders at 200 W-80 °C as shown by lowest Δe value (7.85). Similar findings were reported by Yildiz and Izli (2019). The authors figured out that the dried pomelo pieces exposed to microwave-convective drying displayed the highest lightness values and closest colour values to the fresh pomelo slices (Yildiz and Izli 2019). Colour is an important quality sign for the evaluation of the excellence of dried food materials. In the majority of fruits, colour degradation is distinguished by serious browning, which could be arise from either enzymatic or nonenzymatic origin. Browning is getting bad at higher drying degrees. The favored colors are those closest to the original color of fresh pumpkin slices. These samples can be classified as more preferred and acceptable foods by

Table 4 Colour values of the dried pumpkin powders

Drying method	Colour parameters					
	*L**	*a**	*b**	*C*	α°	*Δe*
Fresh	70.43 ± 0.82^{a}	15.72 ± 0.64^{h}	46.02 ± 0.58^{g}	48.64 ± 0.60^{h}	71.17 ± 0.73^{a}	-
CVD						
60 °C	61.31 ± 3.95^{d}	24.82 ± 1.20^{b}	56.43 ± 2.83^{d}	61.65 ± 3.07^{d}	66.29 ± 0.13^{g}	17.22 ± 0.77^{c}
70 °C	64.71 ± 1.93^{c}	18.81 ± 0.33^{fg}	49.59 ± 1.33^{f}	53.04 ± 1.34^{g}	69.26 ± 0.29^{d}	7.72 ± 0.81^{g}
80 °C	68.22 ± 2.74^{ab}	25.07 ± 0.72	57.65 ± 1.77^{cd}	62.87 ± 1.90^{cd}	66.53 ± 0.09^{fg}	15.29 ± 1.35^{d}
MWD						
100 W	66.16 ± 2.96^{bc}	26.78 ± 0.85^{a}	58.46 ± 2.07^{c}	64.30 ± 2.23^{bc}	65.42 ± 0.14^{h}	17.5 ± 1.17^{c}
200 W	67.85 ± 3.52^{ab}	20.75 ± 0.68^{e}	53.22 ± 1.94^{e}	57.13 ± 2.05^{ef}	68.73 ± 0.14^{e}	9.87 ± 1.23^{f}
MWCVD						
100 W-60°C	67.89 ± 3.35^{ab}	20.58 ± 0.72^{e}	53.22 ± 2.15^{e}	57.06 ± 2.25^{ef}	68.89 ± 0.28^{e}	9.75 ± 1.37^{f}
100 W-70°C	63.64 ± 3.34^{cd}	23.38 ± 0.97^{c}	53.99 ± 2.41^{e}	58.83 ± 2.58^{e}	66.62 ± 0.23^{f}	13.56 ± 0.79^{e}
100 W-80°C	65.68 ± 3.86^{bc}	19.15 ± 0.79^{f}	53.29 ± 2.27^{e}	56.62 ± 2.38^{f}	70.27 ± 0.30^{b}	9.26 ± 1.58^{f}
200 W-60°C	61.15 ± 2.84^{d}	22.63 ± 0.71^{d}	60.92 ± 2.40^{b}	64.99 ± 2.48^{b}	69.65 ± 0.23^{c}	19.19 ± 0.79^{b}
200 W-70°C	64.05 ± 2.14^{c}	23.58 ± 0.39^{c}	63.88 ± 1.65^{a}	68.09 ± 1.66^{a}	69.77 ± 0.29^{c}	20.67 ± 0.91^{a}
200 W-80°C	68.87 ± 2.12^{a}	18.22 ± 0.29^{g}	51.21 ± 1.43^{f}	54.36 ± 1.43^{g}	70.44 ± 0.30^{b}	7.85 ± 0.43^{g}

$^{a-g}$Means superscript with different alphabets in the same column differ significantly ($p \le 0.05$)

consumers related to colour quality. From that way of thinking, dried pumpkin powders by microwave-convective drying is a satisfying application as the samples exposed to this drying technique are resulted in closest colour parameters to the fresh pumpkin fruits compared to the other drying methods.

Bioactive compounds

The changes in ATC (DPPH and ABTS) of dried pumpkin powders are demonstrated in Table 5. A significant ($p \le 0.05$) loss in DPPH was determined in all dried pumpkin powders except the microwave-convective dried pumpkin powders, namely 100 W-60 °C, 200 W-60 °C and 200 W-80 °C. On the contrary, a significant increase ($p \le 0.05$) in ABTS for each and every dried pumpkin powders was observed, especially for the pumpkin powders dried at 200 W-80 °C by MWCVD. The DPPH value of fresh pumpkins was found as 14.14 µmol TE/g on dry basis. On the other way, the DPPH was determined between 9.07 and 20.73 µmol TE/g on dry weight for the dried pumpkin powders. The highest ABTS was observed for the microwave-convective dried pumpkin powders at 200 W-80 °C (Table 5). Larrauri et al (1997) identified the decline in the antioxidant capacity of dried red grape fruit. The decline in ATC can be corresponded to the lower quantity of phenolics substances. In various research, it was announced that there is a direct relationship between total phenolics and ATC in many fruits and vegetables, for instance apricot (Sultana et al. 2012) and pomelo (Yildiz and Izli 2019). In current work, it was also observed the synergetic effect between TPC and ABTS. While the pumpkin powders demonstrated both higher TPC and ABTS, the fresh pumpkins displayed the lowest TPC and ABTS (Table 5). This is thought to be the result of antagonistic or synergistic impacts that may occur among antioxidant components or other compounds during the drying process (Di Scala et al 2011). Yildiz and Izli (2019) figured out that the high antioxidant capacity of foods might be contributed to the synergistic impacts of natural phenolic substances. In overall, the highest TPC and ABTS was observed for microwave-convective dried pumpkin powders at 200 W-80 °C.

Drying application may diminish nutrients in fruits and vegetables because of long drying periods and high temperatures (Fernandes et al 2008). Phenolic substances are bioactive metabolites in fruits and vegetables which attribute to sensorial features such as taste, flavour, colour and functional properties such as antioxidant, antidiabetic, and anticancer activities of food materials (Fernandes et al 2008). In accordance with the statistics, the total phenolic substances of dried pumpkin powders were significantly effected by the drying methods (Table 5). The total phenolic compounds of microwave-convective dried pumpkin powders were significantly higher in opposition to those which were dried by convective and/or microwave alone methods (Table 5). Because of the phenolics are related to the colour, taste, and nutritive quality of food stuffs, its

Table 5 5-Hydroxymethyl-2-furfural (HMF), total phenolic content and antioxidant capacity (DPPH and ABTS) of the dried pumpkin powders

Drying method	HMF content(mg/kg dw)	Total phenolic (mg GA/100 g dw)	DPPH (µmol Trolox/g dw)	ABTS (µmol Trolox/g dw)
Fresh	–	602.49 ± 10.12^{gh}	14.14 ± 1.52^{cd}	47.65 ± 5.11^{h}
CVD				
60 °C	15.72 ± 1.39^{def}	582.88 ± 5.95^{hi}	11.06 ± 0.20^{gh}	78.64 ± 4.28^{cd}
70 °C	16.95 ± 0.46^{d}	562.88 ± 11.55^{i}	13.19 ± 0.10^{def}	73.49 ± 2.89^{de}
80 °C	25.27 ± 0.54^{a}	673.34 ± 13.09^{f}	12.4 ± 0.56^{efg}	81.61 ± 1.00^{c}
MWD				
100 W	15.81 ± 1.08^{def}	819.04 ± 15.12^{d}	11.94 ± 0.19^{fg}	67.19 ± 1.10^{f}
200 W	16.13 ± 1.07^{de}	1020.92 ± 18.37^{c}	10.26 ± 0.16^{hi}	61.41 ± 1.42^{g}
MWCVD				
100 W-60°C	19.22 ± 1.23	623.83 ± 13.50^{g}	15.57 ± 0.23^{b}	73.28 ± 1.95^{e}
100 W-70°C	22.35 ± 1.76^{b}	584.78 ± 14.84^{hi}	9.07 ± 0.15^{i}	91.5 ± 2.98^{b}
100 W-80°C	13.80 ± 0.34^{fg}	1097.1 ± 28.62^{b}	9.22 ± 0.13^{i}	126.78 ± 5.65^{a}
200 W-60°C	11.86 ± 1.40^{g}	785.71 ± 15.73^{e}	20.73 ± 0.24^{a}	63.81 ± 2.34^{fg}
200 W-70°C	11.80 ± 1.43^{g}	769.52 ± 14.09^{e}	13.36 ± 2.30^{de}	68.28 ± 0.18^{ef}
200 W-80°C	10.12 ± 1.78^{h}	1277.08 ± 28.18^{a}	14.91 ± 0.17^{bc}	126.99 ± 3.31^{a}

$^{a-I}$Means superscript with different alphabets in the same column differ significantly ($p \leq 0.05$)

presence is a fundamental biological attribute. Similar to the ABTS, a significant ($p \leq 0.05$) increase in the total phenolic substances was detected in the dried pumpkin powders compared to the untreated pumkin fruits (Table 5). A significant loss ($p \leq 0.05$) in TPC was determined for the pumpkin powders dried by convective alone treatment at 60 and 70 °C. The reduction in the TPC of dried pumpkin powders could be related to the decomposition of heat liable phenolics. Opalic et al (2009) pointed out that the sugar content and bioactive components of dried apple fruit pieces were decreased compared to the fresh sample. It was stated that the microwave-convective dried pomelo samples exhibited higher TPC compared to the microwave alone drying (Yildiz and Izli 2019). Similar to this work, the highest TPC was observed in microwave-convective dried powder pumpkins at 200 W-80 °C. Microwave-convective drying led to increase the content of phenolic substance by the release of phenolic substances bound in the cell wall by the reason of the degradation in the cell wall matrix and / or the formation of new phenolic compounds in behalf of the Maillard reaction (Yildiz and Izli 2019). Different works are exploring the impact of drying process on phenolic compounds. Some studies announced that the drying process caused a decrease in the total phenolic substance content of dried food (Zanoelo et al 2006). In some studies no significant changes were identified (Dewanto et al 2002), and finally some studies reported the significant increase (Yildiz and Izli 2019). As a result of the applied heat treatment, while some phenolic compounds have losses, some of them can become free. Therefore, it can be said that drying process on different products does not have the same effect on the total phenolic substances. In shortly, it was found that both the ATC and the phenolic compounds of the pumpkin powders subjected to microwave-convective drying were higher compared to the fresh and other dried samples.

HMF level is an another significant quality criteria of dried foods. The changes in HMF of dried pumpkin powders are demonstrated in Table 5. A significant change ($p \leq 0.05$) was determined for the pumpkin powders dried by different methods in their HMF contents. HMF is a furanic component which develops as an intermediate in the Maillard Reaction and from direct dehydration of sugars at acidic circumstances during thermal process employed to the fruits and vegetables (Kroh 1994**).** In acidic circumstances, HMF may develop even at low temperatures even though its concentration seriously rises as temperature of thermal processing or storage conditions. According to Rada-Mendoza et al (2004)**,** the HMF analysis by heat treatments might caused Maillard reaction and caramelization of sugars in the acidic conditions of persimmon fruits, and hence, different amounts of HMF might be found in the fruits. All along microwave drying, it seems that the level of HMF in the foods changed remarkably relying upon the MW output power. While the HMF content of dried pumpkin powders was found as 15.81 mg/kg at 100 W, it was observed as 16.13 mg/kg at 200 W. Hebbar et al (2003) studied the HMF level of honey specimens by 21.8% initial moisture composition following the microwave treatment at several power degrees (3.5–16 W/g) for a minute and reported a rise in HMF level with increasing power levels. The highest HMF content was observed for CV-dried pumpkin powders at 80 °C (Table 5). The major cause for the higher HMF levels in

CV-dried pumpkin powders might be the longer time of heat treatment with the comparison of MW and MWCV-dried pumpkin powders. HMF is also connected with the browning occurrence of pumpkin powders, which were subjected to heat treatments. The L^* value was determined highest in MWCV-dried pumpkin samples with the lowest HMF levels in comparison with the other pumpkin powders. Within all dried pumpkin powder samples, the lowest HMF level was found in the specimens dried by MWCVD at 200 W-80 °C (Table 5). This sample showed the highest antioxidant capacity as well. In shortly, antioxidant capacity in the food matrix explored in the current work could have a role for the prevention of HMF production.

Conclusion

In present research, the MWCV-dried pumpkin powders demonstrated a higher retention of bioactive compounds with an improved physicochemical features and color in comparison with other pumpkin powders. By figuring out the influences of drying methods on the quality retention of the dried pumpkin powders, the most appropriate microwave power and temperature combination were determined as 200 W-80 °C to get high quality dried pumpkin powders. The results collected during the current experiments and analysis show that good quality fruit powders with an optimum water activity could be developed by combined microwave-convective drying, which indicates the considerable potential for the use of those powder particles in the food sector.

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Declarations

Conflict of interest There is no conflict of interest to report for the authors.

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