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Effectiveness of the fountain-microwave drying method in some selected pumpkin cultivars

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A B S T R A C T

Nowadays, the least invasive methods of pumpkin drying are sought. They include the microwave drying technique that applies energy carried by short electromagnetic waves for heating and thus dehydrating the material. In the study, five pumpkin cultivars of the species *Cucurbita moschata* and *C. ficifolia* were dried using the new fountain-microwave method. As a result, dry material was obtained whose stress resistance was 10–30 times lower than that of raw pumpkin. It also had 2 times lower resistance to cutting compared to the raw material, especially for the cultivars 'Butternut Waltham', 'Muscade de Provence' and 'Cabello de Angel'. The content of bioactive compounds and antioxidative properties were found to depend on the microwave power applied. Pumpkins dried at 100 W were characterized by greater content of bioactive compounds, but had markedly higher water activity, which is not desirable in dry products. The highest antioxidant activity was found for 'Butternut Waltham' cv. and the lowest for 'Muscade de Provence' cv., although the latter had the highest carotenoid content. The antioxidant activity was decisively more affected by polyphenols than carotenoids.

1. Introduction

The most common drying method is the convection method. In this method the drying factor at the same time provides heat to the material and removes water in the form of vapor. It is a time-consuming but relatively cheap method. For a long time the product is exposed to high temperature, being in contact with oxygen contained in the air. Under such conditions there follows reduction of the valuable components sensitive to oxidation at high temperature. An additional disadvantage of the method is considerable drying shrinkage and unwelcome changes in smell, flavor, nutrient content and reconstitutional characteristics (Lin, Durance, & Scaman, 1998). For this reason, the search is ongoing for new methods of drying plant material.

Such innovative techniques for drying of pumpkin include the fountain method. Being only the setting of the dried material in movement of known trajectory, it allows significant shortening of drying time compared to the classic convective drying. In addition, the heating of the material is more uniform, the transport conditions of heat and mass improve, so that the duration of the process shortens and the dried material is of higher quality (Bezerra, Amante, Cardoso de Oliveira, Rodrigues, & Meller da Silva, 2013; Kahyaoglu, Sahin, & Sumnu, 2012).

In the search for techniques that will help obtain products of the highest quality, there has been developed a large group of combined methods of drying with the use of microwave-supplied heat for dehydrating a material. Microwave heating is used for the convective (Lentas, Witrowa-Rajchert, & Hankus, 2011), sublimation (Cohen and Yang, 1995), and fountain drying (Feng, Zhang, Jiang, & Sun, 2012; Kahyaoglu et al., 2012). Drying with combined methods allows one to shorten multiple times the duration of the process, and the dry materials are characterized by minimal biochemical changes, less drying contraction, and increased hardness and water affinity of the product. The dry materials are of better quality than products obtained using other drying techniques (Wang, Xi, & Yu, 2004; Yan et al., 2010).

A good raw material for the drying industry is ripe pumpkin fruits mainly belonging to the species *Cucurbita maxima* considered to be a source of healthy substances. Pumpkin slices are usually dried by the convective method (Nawirska, Figiel, Sokół-Łętowska, Kucharska, & Biesiada, 2009; Sojak & Głowacki, 2010), sometimes

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preceded by osmotic drying (Garcia, Mauro, & Kiura, 2007), which is also used before vacuum drying (Arévalo-Pinedo and Murr, 2007). Pumpkin slices were also dried by the microwave method (Alibas, 2007).

In Poland and all over the world there is increasing interest in the cultivation and processing of pumpkin belonging to different species. The flesh of pumpkin, regardless of cultivar, is characterized by low calorific value (ca. 140 kJ/100 g) combined with high nutritional value which largely depends on the genus and cultivar (Nawirska-Olszańska, 2011).

In the fresh mass of the fruit, total carotenoid content, a major contributory factor in the high nutritional value of pumpkins, ranges from 0.2 to 18.5 mg/100 g; the content of vitamin C from 3.7 to 45.9 mg/100 g and total phenolics from 9.9 to 476.6 mg GAE/100 g (Jacobo-Valenzuela, Maróstica-Junior, Zazueta-Morales, de, & Gallegos-Infante, 2011; Nawirska-Olszańska, 2011). Among the carotenoids, the fruit of musk pumpkin contains the largest amounts of α- and β-carotene as well as lutein and cryptoxanthin. Pumpkin fruit is also a valuable source of other vitamins, e.g. B_6, K, thiamine, and niacin, as well as minerals, e.g. potassium, phosphorus, magnesium, iron and selenium (USDA National Nutrient Database, 2010).

Butternut, popular in cultivation in many warmer parts of the world, in Poland is little known and cultivated only by amateurs. The bottle shape of the fruit of certain varieties of musk pumpkin (Butternut) allows us to separately operate and process the seed-free parts of the fruits, while the remainder can be used for the manufacture of animal feed, or other purposes. The *C. maxima* and *C. moschata* varieties serve for production of dry material in the form of flour to be added to many foods as a functional additive (Lee et al., 2002).

The present work uses a new method for drying pumpkin slices, which is the fountain-microwave method. The aim was to determine selected mechanical features, chlorophyll and carotenoids content, as well as general polyphenols and antioxidant properties, and also water activity in dry slices of 5 cultivars of pumpkin dried with the fountain-microwave method at 100 and 250 W.

2. Materials and methods

2.1. Plant material

The field experiment was carried out in a Research and Development Station of Vegetables and Ornamental Plants at Psary near Wroclaw, on clay soil containing 1.8 g/100 g humus and of pH 6.9. Pumpkin seedlings produced in a warmed greenhouse were planted in the field on 20 May and the fruit was harvested at physiological maturity on 20 September. Slices of pumpkin flesh obtained from 4 cultivars with orange flesh belonged to the species *C. moschata* (Butternut Waltham, Llena de Napoles, Muscade de Provence and Butternut Rugosa) and 1 cultivar with white flesh Cabello de Angel belonging to *C. ficifolia*. After removing the skin, cylinders of 5 mm height and 20 mm in diameter were cut from the flesh of pumpkin.

2.2. Fountain-microwave drying

Fountain-microwave (FM) drying was done using a prototype installation, whose scheme as shown in Fig. 1. A detailed description of the construction and principle of action is described in the publication by Pasławska, Stępień, Jałoszyński, Surma, and Magganos (2013). The drying was at air speed varying from 4 to 10 m s^{-1}. Reduction of flow speed of the drying agent is necessary to preserve a stable fountain effect. The drying agent temperature was 70 °C (Feng, Tang & Cavalieri, 2012; Feng, Tang, Mattiinson, & Fellman, 1999; Kahyaoglu et al., 2012; Nindo, Sun, Wang, Tang, & Powers, 2003). Microwave power was 100 or 250 W.

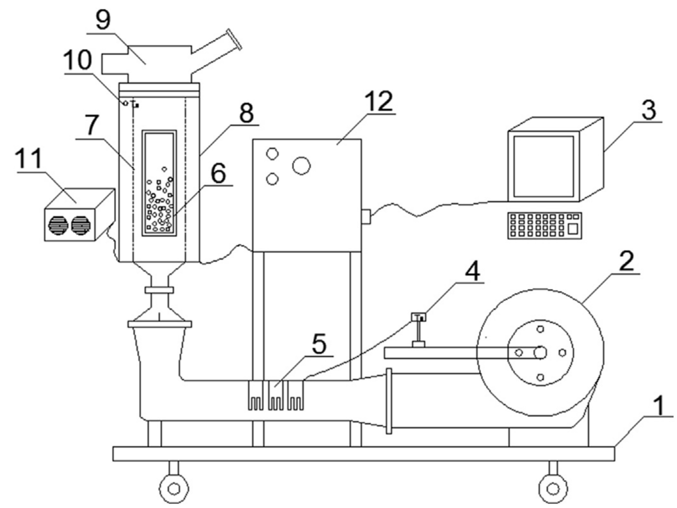

Fig. 1. Installation for fountain-microwave drying. *1 – device base with wheels, 2 – fan, 3 –computer, 4 – temperature sensor, 5 – heater, 6 – dried material, 7 – drying chamber, 8 – metallic protection, 9 – cover, 10 – thermocouple sensor, 11 – microwave generators, 12 – control cabinet.*

2.3. Determination of total phenolic content

Samples for the analysis of polyphenols were prepared as follows: approximately 2.5 g of each pumpkin fruit was weighed into a test tube for antioxidant analysis. A total of 25 mL of 80 mL/100 mL aqueous ethanol was added, and the suspension stirred slightly, sonicated for 15 min, and left at 4 °C. After 24 h the extract was centrifuged at 12,500x*g* for 5 min, and the supernatants were recovered.

Total polyphenols (TPC) were determined by the Folin-Ciocalteu method (Lachowicz, Kolniak-Ostek, Oszmiański, & Wiśniewski, 2016), using gallic acid (GA) as a standard for the calibration curve. After 1 h the results were read at 765 nm in a spectrophotometer (Shimadzu UV-2401 PC). All determinations were performed in triplicate. The results of the assay were calculated and expressed as milligrams of GA equivalent (GAE) per 100 g dry matter (DM).

2.4. Antioxidant activity

2.4.1. $ABTS^+$ radical scavenging spectrophotometric assay

$ABTS^+$ radical scavenging activity was measured according to the method developed by Re, Pellegrini, Proteggente, Pannala, and Yang (1999). The $ABTS^+$ solution was diluted with redistilled water until the absorbance of 0.700 (0.02) at 743 nm was achieved. Upon addition of 60 μL of the extract (obtained in the same manner as total polyphenols) to 3 mL of diluted ABTS + solution, absorbance was read exactly 6 min after initial mixing in the spectrophotometer. All determinations were performed in triplicate.

2.4.2. Ferric reducing antioxidant power (FRAP) assay

The reducing potential of the sample was determined using the FRAP assay, proposed by Benzie and Strain (1996), as a measure of antioxidant power. An antioxidant reduces the ferric ion (Fe^{3+}) to the ferrous ion (Fe^{2+}); the latter forms a blue complex (Fe^{2+}/TPTZ), which increases the absorbance at 593 nm. The extract (0.30 mL) and FRAP reagent (3 mL) were added to each solution and mixed thoroughly. Absorbance was taken at 593 nm after 10 min. A standard curve was prepared using different concentrations of