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Drying kinetics and selected physico - chemical properties of fresh cranberries preserved with microwave - vacuum process

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Abstract

A one stage drying process for dried cranberry production, employing a vacuum microwave technique, is proposed. The process consists of a specific sequence of microwave energy dosage at a given vacuum level. During the 60 minute process, three sub-stages can be identified: osmotic dehydration, intensive water evaporation and stabilization. Mass transfer, as well as quality changes during the process, has been described, and the final product quality compared to purchased control. The proposed method of dried cranberry production resulted in a microbiologically stable product (a_w=0.62) of a decent sensory quality, with an antioxidant potential three times higher than traditional products.

Keywords: *Vaccinium macrocarpon; microwave-vacuum drying; ready-to-eat snack*

1. Introduction

The cranberry (*Vaccinium macrocarpon*) fruit is recognized worldwide as a rich source of numerous phytonutrients with confirmed pharmacological and antioxidant properties [1]. Due to a high acid content, as well as an astringent taste, the fresh fruits are unacceptable for direct consumption. In an effort to make cranberries more appealing to consumers, one idea is to dry them, which unfortunately also means adding sugar. The traditional method of dried cranberry production is a time and energy-consuming process, which is realized in three stages: skin pre-treatment, sugar infusion by osmotic dehydration and final drying. Cranberry fruits, like many other fruits are covered by a cutin layer consisting of fatty acid polymers which exist to protect the fruit from losing water. Although the wax layer is beneficial in plant biology, it restricts processing by inhibiting osmotic dehydration and further drying processes. Cutting the fruits into halves allows the interior fruit tissue to be exposed to osmotic solution as well as increasing the evaporation surface during final hot air drying. Sadly, cutting the fruit also leads to several negative consequences, such as a higher leakage of sap or an increase in nutrient oxidation during the final drying. Available literature documents numerous attempts to intensify the osmotic dehydration of cranberries through various pre-treatments [2–3], as well as attempts to accelerate the drying process by applying new drying techniques [4–6]. Among the new techniques, a hybrid technique including microwave technology has been intensively investigated [7]. According to the latest reports the drying time can be reduced to less than 100 min [3]. The other problem associated with dried sweetened cranberry production is the time needed to infuse sugar, which can take up to 24 hours [8]. Despite the introduction of some new ideas to reduce the osmotic dehydration process [3,5], the waste sucrose syrup collected after the process, remains a serious technological and environmental problem.

The aim of this paper is to present an idea combining sugar infusion and final drying of freshly cut cranberry fruit, which can be realized within 60 min in the same reaction chamber by using a vacuum microwave technique.

2. Materials and Methods

Cranberry fruits (`Ben Lear` cv) taken out of cold storage (2°C) were thoroughly washed with tap water and cut in half. The osmo-dried cranberry production was realized using a laboratory vacuum-microwave dryer (PromisTech, Wrocław, Poland). The standard polypropylene reaction chamber was replaced with a glass drum, which allowed the management of liquid medium. Just before drying, a batch of 100 g freshly cut cranberry fruit halves were placed into a 2 L capacity glass drum and mixed with 80g of 40% sucrose solution. When the system reached the ambient temperature (20.0 ± 2.0°C), the process was started. The drying procedure was developed using a specific sequence of microwave energy

dosage at a given vacuum level. The drying period lasted 60 min, within which, three sub-stages can be identified, as is presented in Table 1 (PL, Patent Pending, 2018).

Table 1. The technical parameters of the vacuum microwave drying of halved fresh cranberries

Stage	Duration [min]	Operation	Preasure [hPa]	Max sample temperature [°C]	Microwave power [Watt/g]
1	15	Osmotic dehydration	30 ± 2	34.0 ± 0.8	1.00
2	30	Evaporation	30 ± 2	57.0 ± 3.0	3.25
3	15	Stabilization	6 ± 2	30.0 ± 1.0	0

The density of microwave power introduced into the drying chamber ensured that the material temperature was kept below 60°C. The mass transfer, and the quality changes of the material, was monitored in 7 mid-points, after 5, 10, 15, 20, 30, 35, 45 min and after process completion. To follow real drying dynamics, the process was terminated after a given time, and the material collected for analyses, after which a new procedure with a new batch of raw material was begun. For each mid-point of the process water removal rate was determined as the difference between the total weight of material at the given point. The material temperature was measured by a manual pyrometer, and then the material was checked for moisture content, density, anthocyanin content and antioxidant capacity. The appearance of the material was captured by a camera. The fruit samples taken between 5-30 min of the process, prior to measurement, were gently rinsed with water to remove residual syrup and blotted with paper towels. A fresh portion of fruit was used to obtain each sample taken for each time interval. The final product quality was also evaluated by a sensory panel, and the experimental dried fruit were compared to dried cranberries purchased in the market (one bulk product and one commercially packed). The experiment was carried out in two technological repetitions.

2.1. Physical, chemical and sensory analyses

The dry matter content was determined using the gravimetric method by drying the sample to a constant weight at 70°C under vacuum conditions (3 kPa) according to PN-90/A-75101/03 [9]. The density of the dried berries was determined using hydrostatic scales (Radwag) and calculated using the following formula:

$$\rho_s = \frac{ms_1}{\mathrm{ms}_1 - \mathrm{ms}_2} * \rho_t$$

where, ρ_s indicated sample density (g/cm^3), ms_1 sample mass in the air (g), ms_2 sample mass in toluene (g), and ρ_t density of toluene (g/cm^3). For each experimental point the measurements were repeated for 6 individual fruit halves.

Water activity was measured 24 h after drying, using HC2-AW-USB station probes connected to a PC running HW4-P-QUICK-V3 software (Rotronic, B&L, Poland).

Antioxidant activity was determined according to the method described by Re et al. [10]. Measurements were recalculated to micromoles of Trolox equivalents per gram of dry weight (µmol Trolox/g DW).

Total anthocyanin content was quantified using the pH differential method [11]. The results were calculated as cyanidin-3-glucoside, and expressed in mg/100 g DW of the analyzed sample. For each mid-point of particular technological repetition, two independent analytical replicates were carried out.

Sensory analysis. Both experimentally dried fruit and the commercially purchased products were assessed by a well-trained panel using a profiling method. The samples were evaluated in individual sensory booths under white light (6500 K). All samples, marked with 3-digit codes, were served in duplicate in random order. Panelists were asked to evaluate fifteen sensory attributes: three aroma attributes (fruity, untypical, overall), two textural attributes (hardness and overall), five flavour/taste attributes (fruity, sweet, sour, astringent, bitter, and off-flavour) and overall flavour, as well as overall quality. The results were finally expressed in 10-point scale.

2.2. Statistical analysis

The data was processed using the STATISTICA 13.0 software package (StatSoft Inc., Tulsa, USA). To determine the difference between experimental and commercial products the analysis of variance (ANOVA) and a Duncan´s multiple range test at $p = 0.05$ was used.

3. Results and Discussion

The dehydration kinetics of the fresh cranberry halves subjected to the one stage process realized in a vacuum- microwave reactor is illustrated in Fig. 1. Along with the parameters outlining the mass transfer intensity, the sample temperature is also given (Fig 1A). As the drying process proceeded simultaneously with osmotic dehydration, the obtained drying kinetics presents an untypical shape. In the first 15 min of the process, the drying rate gradually decreased (Fig. 1B), probably due to the effect of the increase of the syrup viscosity surrounding the surface of the fruit. During this stage the soluble solids of the fruit increased from 8.9 ± 0.1 to 15.1 ± 1.1°Brix, which was also reflected by the increase of the sample dry matter (Fig. 1A), caused mainly by the infusion of sugar into the fruit. The predominant effect of the osmosis mechanism at this stage, is indicated by the very low WRR (Water Removal Rate), which after 15 min of the process reached the minimum.

When the residue of syrup liquid had run out, the second stage of drying was initiated by a microwave power increase up to 3.25 Watt/g of the initial sample weight. Immediately, the

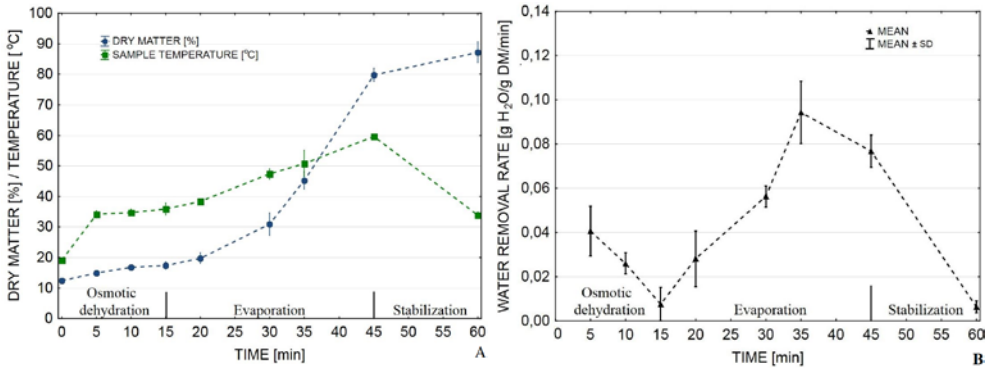

Fig. 1 Diagram of changes monitored for osmo-dehydrated cranberries during drying process (A) material temperature and dry matter contents (B) water removal rate, MEAN ± SD (n=2)

WRR accelerated, and the water evaporation intensity increased for about 20 min, until it gained a maximum value of 0.094 g H_2O/g DM/min, after which the WRR started to decline, and despite the still relatively high water content (2g H_2O/g DM) in the dried material, the sample temperature continued to rise. When the temperature was approaching 60°C, the MW power was automatically reduced to avoid overheating. The temperature limit was set on the basis of other authors work [12], where 60°C is reported as crucial in polyphenol degradation in sour cherries subjected to microwave-vacuum drying. After 45 min of the process the microwave power was switched off, but water evaporation still occurred, with a steadily decreasing WRR, which can also be attributed to the low water content in the sample. These observations follow the typical pattern of sample temperatures when fruits are subjected to microwave drying [8,13].

In Fig. 2 the quality changes of the dried material during the dehydration process are presented. During the first twenty min the sample density rose from the initial value of 0.87

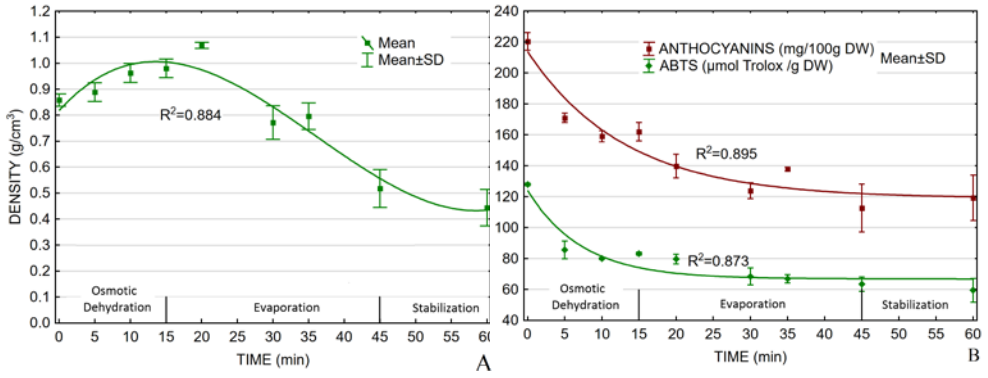

Fig. 2 Trends in the quality changes of osmo-dehydrated cranberry fruit during the drying process: (A) fruit density; (B) anthocyanin content and antioxidant activity ($ABTS^{\bullet+}$), MEAN ± SD (n=2).

± 0.02 to over 1 g/cm^3 (Fig. 2A), which indicates slight material shrinkage, as is illustrated in Photo 1 (B).

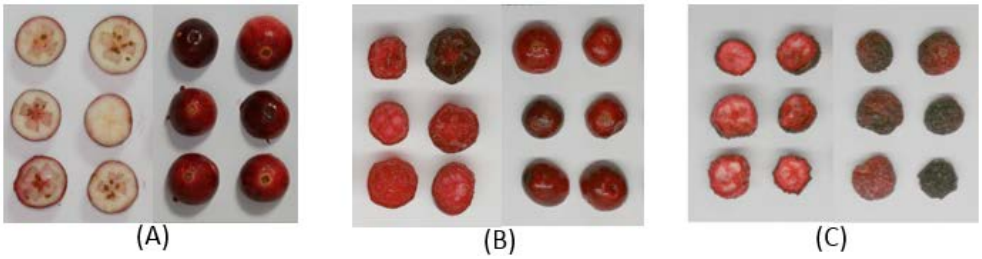

Photo 1. Cross-section and outside appearance of raw material (A), osmotically infused fruits after 15 min (B) and final product (C).

To some extent, the increase in the density of the material can be explained by the fact that the intercellular spaces were replaced by the infused sugar syrup. In the next 40 min the fruit density decreased steadily, by up to 0.48 ± 0.02 g/cm^3, which represents almost half the initial density of the fresh material. This phenomena is typical for vacuum drying, where rapid mass transfer is accompanied by a typical expansion in a so-called "puff up" effect [14]. In Fig 2B, the effect of process time on the bioactive component content is presented. The raw material used in the study contained on average 220 ± 4 mg/100 g DW of total anthocyanins, which means that cranberries grown in Poland are able to accumulate as much anthocyanin as the Canadian clones [15]. Although the drying process lasted only 60 min, and the sample temperature did not exeed 60^{o}C, the evident negative effect on both anthocyanin content and antioxidant activity (ABTS$^{\bullet+}$) was observed. When compared to fresh fruit, the loss of anthocyanins reached almost 50%, and its final content in dried product amounted to 119 ± 10 mg/100g DW. A similar pattern was found for antioxidant activity, which decreased from 127 ± 0.2 to 57 ± 1.3 μmol Trolox/g DW (Fig. 2B). According to data in literature, anthocyanin degradation in halved cranberries is higher than for sour cherries dried in similar microwave-vacuum conditions [15]. As is clearly presented in Fig. 2B, the antioxidant activity of dried cranberries expressed by ABTS$^{\bullet+}$, corresponds with the gradual decrease in anthocyanins. Similar findings have been reported by other authors [13,16] who indicated the anthocyanin content as having a major impact on the total antioxidant capacity of the cranberry fruits.

To be able to identify the advantages of our product, the experimental material (Photo 1, C) was compared to commercially available product. The comparison comprised sensory attributes, antioxidant properties and water activity. The results are gathered in Table 2. Sensory evaluation of the product showed that, when compared to commercial products, the experimental cranberry (MW-V) was characterized by a more intensive fruity aroma, but unfortunately, despite higher water activity, also by an inferior texture. It was also perceived

as less sweet, which resulted in a rating of only 4.8 (out of 10) in the overall quality assessment.

Table 2. The comparison of chosen quality characteristics of dried cranberries available in the market and the experimental product (MW-V).

Product type	Sensory attributes (0-10 points)							
	Fruity aroma	**Fruity flavour**	**Sourness**	**Overall texture**	**Sweetness**	**Overall quality**	**ABTS [µmol Trolox/g fresh weight]**	**Water activity**
Bulk product	2.8^{b*}	4.8^{b}	3.3^{a}	7.4^{b}	6.2^{b}	6.8^{b}	15.0^{b}	0.55^{a}
Commercially packed	1.5^{a}	3.7^{a}	2.7^{a}	7.1^{b}	6.2^{b}	4.9^{a}	9.9^{a}	0.54^{a}
MW-V	3.1^{b}	4.9^{b}	5.8^{b}	4.9^{a}	4.4^{a}	4.8^{a}	51.8^{c}	0.62^{b}

**Means in columns marked with the same letter do not differ significantly according to Duncan MRT at p = 0.05.*

Surprisingly, the highest overall quality was indicated for commercial, unpacked cranberries, which were expected to be of lower quality than the packed ones, which were assessed as having an untypical aroma and being off-flavour, which can be attributed to the flavor of oxidized oil, resulting in a low sample acceptance. Despite a slightly lower sensory appreciation than the commercial product, the dried cranberry produced using our method was characterized by three times more antioxidant potential. The $ABTS^{\bullet+}$ values seen in the experimental product were on average 51.9 ± 5.5 (Table 2), whereas for cranberries purchased in the market the values were as low as 15.02 ± 0.2 and 9.88 ± 0.2 µmol Trolox/g fresh weight for the bulk product and commercially packed, respectively.

4. Conclusions

The proposed method of sweetened dried cranberry production resulted in a microbiologically stable product (a_w = 0.62) after a 60 min process. Sensory evaluation of the product showed that compared to commercial products, the experimental cranberry was characterized by a richer fruit aroma, but unfortunately, also by an inferior texture and lower sweetness sensation, which resulted in a rating of only 4.8 (out of 10) in the overall quality assessment. Despite a unfavourable sensory appreciation, the dried cranberry produced using our method was characterized by three times more antioxidant potential, thus further process optimization seems advisable.

We can summarize, that the presented idea of production sweetened ready-to-eat dried cranberries using a one stage process combining osmotic treatment with a vacuum microwave dehydration technique can be considered as an alternative to traditional dried cranberry production.

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