

Intermittent–microwave and convective drying of parsley

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Abstract

The studies present convective drying of parsley with an intermittent microwave application. Eight different drying programs including convective drying (CV) were carried out in a laboratory-scale hybrid dryer. The influence of intermittent conditions on drying time, drying rate, energy efficiency and product quality was analysed. The results demonstrated that intermittent–microwave convective drying improves the drying kinetics and reduces energy consumption. Moreover, a higher retention of vitamin C, smaller color change and a better ability to rehydration were observed for the parsley samples dried using intermittent drying than for CV.

Keywords: *intermittent drying, microwaves, energy, vitamin C, rehydration.*

1. Introduction

Many experimental investigations have shown that combined drying methods result in higher drying effectiveness from both kinetic and quality aspect. Drying based on the combination of various techniques, i.e., hybrid drying, is still an emerging drying technology in food industry. [1, 2] One of the possibilities to improve the drying kinetics and product quality can be intermittent drying. As one of the recommended methods for vegetable and fruit dehydration, consists of drying at non-stationary conditions, where the process parameters change periodically in time, e.g. varying temperature or varying mode of energy input. [3,4] The main aim of this solution is to prevent the loss of product quality and to enhance the energy efficiency. Intermittent microwave-convective drying has the opportunity to develop, as it is competitive to other more expensive alternative methods, such as, for example lyophilization. Parsley (*Petroselinum crispum*) is a popular plant of celery family (*Apiaceae*). Both its roots and leaves are used for culinary, medical and cosmetic purposes. It is a valuable spice vegetable which owes its aromatic properties to the essential oil. Ingredients found in parsley, e.g., vitamin C and E, polyphenols, carotenoids, have strong antioxidant properties, and their presence in the human diet is considered to be an important factor reducing the risk of civilization diseases. [5]

The aim of the studies was to analyze the effectiveness of hybrid drying in non-stationary conditions with respect to process kinetics, energy consumption and quality of dry parsley. The influence of intermittent microwave application in convective drying on the total drying time, drying rate, energy usage and quality characteristics such as colour change (dE), water activity (aw), retention of vitamin C, radial shrinkage (RS) and rehydration capacity (RC) were investigated in this study, and compared with processes carried out in constant conditions (convective and convective-microwave drying).

2. Materials and Methods

Fresh parsley roots (*Petroselinum crispum*) cultivated in Poland were used as a research material. 50g parsley samples in the form of slices (32 mm diameter, 5 mm thick) were dried in a laboratory-scale hybrid dryer equipped with an air-heating system, microwaves (2.45 GHz, max. power of 500 W) generated by a magnetron, pyrometer (infrared thermometer) and a standard electricity meter. The samples with an average initial moisture content of 0.84 kg·kg⁻¹ w.b. were dried to a final moisture content of 0.1 kg·kg⁻¹ w.b. using eight drying programs including convective drying as a reference (Table 1). The first four drying procedures were conducted using stationary conditions (i.e., convective drying (CV) and convective-microwave drying (CVMW)), whereas the next four procedures were performed using non-stationary conditions (i.e. intermittent–microwave and convective drying (IT1-4)). The basis for all IT programs was continuous CV with MW (ON/OFF)



cycles applied at the beginning of each drying test. The drying conditions were changed in terms of the air temperature, number of MW cycles or MW power to avoid overheating of the dried material. The drying processes were operated at 30°C or 50°C, or with a variable air temperature T_a (50°C/30°C). The microwave power was constant and set at 100 W, 300 W or 500 W. Irrespective of the type of drying program, the air velocity was constant throughout the entire process, i.e. 0.4 m/s.

Table 1. Description of the drying programs.

No.	Acronym	Description	T_a [°C]	MW [W]	MW cycles duration
1	CV30	Convective drying	30	0	NA
2	CV50	Convective drying	50	0	NA
3	CVMW30	Convective-microwave drying	30	100	CONT
4	CVMW50	Convective-microwave drying	50	100	CONT
5	IT1	Intermittent drying	50/30	100	ON up to $T_m=50^\circ\text{C}$ / 15 min OFF
6	IT2	Intermittent drying	50/30	100	ON up to $T_m=50^\circ\text{C}$ / 30 min OFF
7	IT3	Intermittent drying	30	500	ON up to $T_m=50^\circ\text{C}$ / 15 min OFF
8	IT4	Intermittent drying	30	300	ON up to $T_m=50^\circ\text{C}$ / 15 min OFF

CV – convection, MW – microwaves, IT – intermittent, T_a – air temperature, T_m – material temperature, CONT – continuous, NA – not applicable

2.1. Process kinetics and energy consumption

The drying kinetics was assessed on the basis of the moisture ratio (MR), drying rate (DR), drying time (DT) and the energy consumption (EC). The parameters were determined as follows:

$$MR = \frac{MC_t - MC_{eq}}{MC_i - MC_{eq}}, \quad (1)$$

$$DR = \frac{dm}{DT}, \quad (2)$$

where: MC_i , MC_t and MC_{eq} are the initial, instantaneous (for a given time of the process) and equilibrium moisture contents, dm is the total weight loss of the sample, and DT is the total drying time, i.e. until the moisture content reaches equilibrium.

The initial moisture content of the raw material was determined using a moisture analyser (XM120 Precisa, Switzerland). Each drying program was repeated in triplicate and the total drying time (DT) was averaged for data interpretation. The energy consumed by the whole apparatus during the drying processes was measured with a standard electricity meter and recalculated to MJ per 1 gram of evaporated moisture. The average EC was determined by:

$$EC = \frac{E_p \cdot 3.6}{dm}, \quad (3)$$

where: E_p is the average energy consumption in kWh measured in drying process, and dm is the total weight loss of the sample.

2.2. Quality assessment

The product quality was assessed in terms of the total colour change (dE), water activity (aw), retention of vitamin C (AA), radial shrinkage (RS) and the rehydration capacity (RC). The total colour change was measured using a colorimeter (CR-400 Konica Minolta, Japan) and indicated using CIELab colour space:

$$dE = \left(dL^{*2} + da^{*2} + db^{*2} \right)^{0.5}, \quad (4)$$

where: L^* indicates lightness and a^* , and b^* are the chromaticity coordinates which indicate color directions from red to green (a^*) and from yellow to blue (b^*).

Water activity (aw) was measured for fresh and dry product at 25°C using the LabMaster-aw Standard (Novasina AG, Switzerland). The measurement of aw for dry samples was conducted after a 24-hour incubation in a desiccator, since the moisture profile needs to be aligned after drying. Retention of vitamin C (AA) in the parsley root was determined by the spectrophotometric method. [6] The Radial shrinkage (RS) was assessed on the basis of image analysis. Photographs taken on the samples were subjected to basic treatment and used in Fiji software (v. 1.51u) for calculation of shrinkage in accordance with equation:

$$RS = \left(\frac{1 - A_d}{A_0} \right) \cdot 100\%, \quad (5)$$

where: A_d and A_0 are the surfaces of dry and raw parsley samples, respectively.

Dried samples were rehydrated in boiling distilled water at temperature of 100°C for 5 min, without stirring. The ratio of material to water was 1:50 (w/w). After rehydration the samples were blotted with a filter paper and weighed. The rehydration capacity (RC), described as percentage water gain, was calculated according to Seremet et al., 2016. [7]

3. Results and discussion

3.1. Drying kinetics

The drying kinetics of parsley root was evaluated on the basis of drying and temperature curves. Figure 1 shows the results of moisture ratio, average drying rate and energy consumption obtained during drying in constant and intermittent conditions.

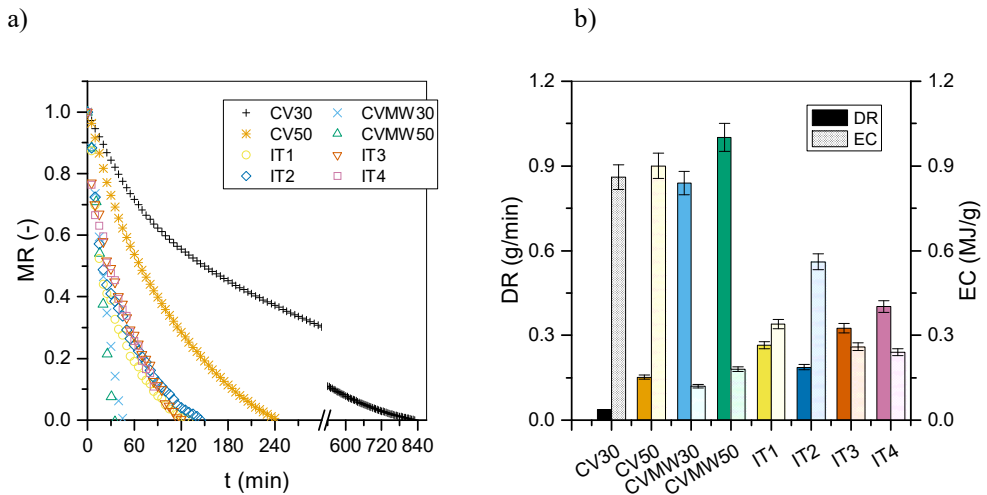


Fig. 1. Moisture ratio MR (a) and average values of drying rate DR, and energy consumption EC (b) for different drying programs.

The CV drying was found to be the longest process as the parsley samples achieved the final moisture content after about 14 and 4 hours for 50°C (CV50) and 30°C (CV30), respectively. As can be seen in Fig. 1b, also CV the smallest value of the drying rate was obtained. The results of hybrid drying, i.e., CVMW, showed a significant reduction in drying time, namely about 95% as compared to CV. Similarly, the average drying rate for CVMW was the highest amongst all the drying procedures. In turn, intermittent drying (IT) demonstrated shorter drying times, namely by 82-86%, in comparison to CV, but on the other hand a considerable increase in DT and lower values of DR than those of the CVMW. As follows from Fig. 1a, longer OFF cycles during IT2 increased the total drying time and thus decreased noticeably the drying rate, as compared to IT1. However, which is surprising, a lower MW power applied in IT4 increased the drying rate in comparison with IT3. In case of the energy effectiveness (Fig. 1b), the lowest energy efficiency was

observed for CV, as the highest EC was obtained. The average energy consumption was definitely lower for all the IT processes, but the highest energy efficiency was found for CVMW. It was noticed that energy usage is proportional to the total drying time.

3.2. Product quality

The quality of parsley samples was evaluated on the basis of several quality characteristics. Figure 2 presents the results of colour change and water activity between fresh and dry product.

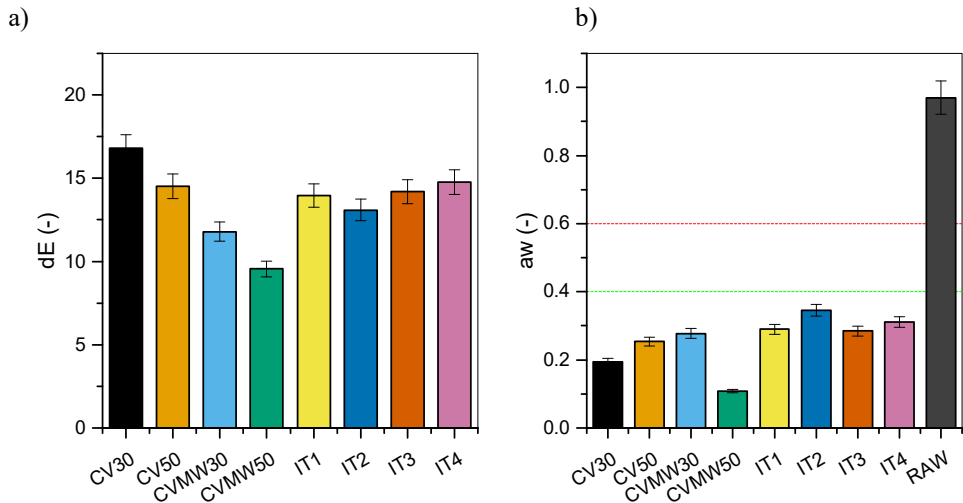
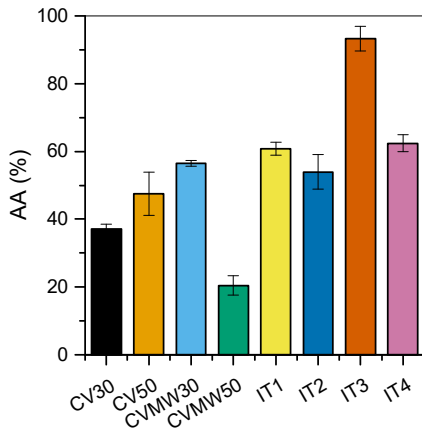


Fig. 2. Total colour change dE (a) and water activity aw (b).

The highest total color change (16.79) was observed for CV30. Thus, the discoloration of parsley was due to continuous and prolonged application of hot air during drying. Astonishingly, despite continuous MW in CVMW, the colour change was visibly lower than for CV as well as for IT. As follows from Fig. 2a, dE after intermittent drying (IT1-4) was found to be similar to that of CV50, i.e. 14, on average. However, the results of colour coordinate (L^*) proved that the overall change in colour for CV and IT samples increased due to higher value of lightness after drying. In consequence, it means a positive change in colour, i.e., “brightening” of the samples dried by CV and IT. The next quality factor was water activity aw (Fig. 2b), which allows to verify the microbiological stability of dry product, e.g., development of microflora, product durability. The fresh material was characterized by the water activity of 0.970, on average. After each drying process water activity was less than its critical value, i.e. 0.6, thus the microbial growth (bacteria, yeasts and molds) was inhibited and biologically stable products were obtained. Secondly, aw of dry parsley samples was lower than 0.4, which means that many reactions, e.g. enzymatic, non-enzymatic (Maillard) and oxidation have been blocked. [8]

Figure 3 presents the results of vitamin C retention, radial shrinkage and rehydration capacity. CVMW50 contributed to the lowest vitamin C retention amongst all the analysed drying programs (Fig. 3a). In turn, for CVMW30 the retention was 57%, and was also higher than for CV. In case of IT, the value of AA was in the range of 54-93%. The highest content of AA was obtained for IT3. In general, intermittent application of microwaves in convective drying allowed the parsley to retain more vitamin C then in case of CV or CVMW.

a)



b)

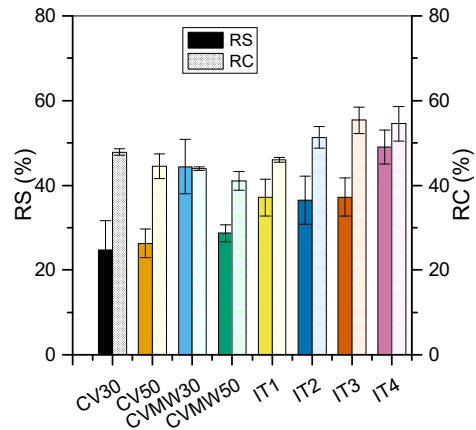


Fig. 3 Retention of ascorbic acid AA (a), radial shrinkage RS and rehydration capacity RC (b).

The results of radial shrinkage (Fig. 3b), showed that type of process may influence the appearance of samples significantly. The products dried in stationary conditions were characterized by a slightly lower RS in comparison to the non-stationary ones. The only exception is CVMW30, where the observed RS was similar as for IT. Nevertheless, the smallest shrinkage was observed for the material dried by CV, regardless of the air temperature. The last quality parameter evaluated in this work was rehydration capacity (RC), which gives information on the ability of the material to absorb water. As follows from Fig. 3b, the rehydration capacity of samples dried by CV and CVMW increased with the decrease of temperature. Therefore, due to the increase in air temperature (i.e., from 30°C to 50°C), a destruction of plant tissue structure must have occurred. In case of IT1-4, a higher RC was observed. Moreover, the value of RC increased with the OFF time and also with MW power applied during intermittent drying.

4. Conclusions

The effect of different methods including non-stationary drying on kinetics and quality characteristics of parsley root was discussed. The results of the drying tests showed that intermittent drying reduces drying time by 86%, increases the drying rate and thus

improves the energy efficiency (up to 80%) as compared to convective drying. Furthermore, it was found that microwaves applied intermittently in convective drying contributes to better product quality from the colour, vitamin C retention and rehydration property point of view.

5. Acknowledgement

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6. References

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