Kinetic and quality characteristics in combined drying of carrots

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Abstract. Drying carrots experiments were carried out at different drying modes in a laboratory convective dryer combined with microwaves. Some empirical regularities in drying process have been obtained - drying curves and drying rate curves. An assessment of the influence of the drying regimes on some quality indicators of the final product was made.

1 Introduction

Carrots are a root vegetable that occupies an important place in a human nutrition. They are the richest source of β-carotene and have excellent dietary qualities. They are used both raw and in a processed state (most often blanched and dried). There are good opportunities for their storage, during which significant changes in the quality of the product can occur [1].

Foods containing provitamin A such as carrots are useful in preventing health problems such as cancer, cardiovascular/coronary heart disease, due to their antioxidant activity. They also help to reduce blindness in children [2].

Drying is one of the common methods of foodstuffs storage [3, 4]. Convective drying is the most widespread drying process. It is characterized by high energy consumption and long duration [3, 4]. The use of hot air as a drying agent has a significant influence on the quality of the dried product [3, 4]. High temperature significantly reduce the duration of the process, but has an unacceptable effect on the texture, color, taste and nutritional value of the products [4, 5]. This necessitates the search for new and different drying methods. The application of microwaves in the drying process or in combination with another drying method would increase the quality of the products, due to the lower duration of the process and the different thermal treatment. The energy efficiency of such processes compared to common convective drying is also important. The use of microwave heating in the drying of heat-sensitive products such as carrots necessitates the investigation of the influence of some additional drying characteristics such as applied power, duration of heating, sample thickness, etc. on β-carotene content and rehydration coefficient [3].

Lavelli at al. [2] have investigated the effect of water activity on the stability of carotenoids in dried carrots. At different storage duration, equilibrium humidity, water activity, α- and β-carotene and lutein content were analyzed. Kinetic dependences were experimentally obtained during the drying of carrots, cut into pieces with dimensions of 40x20x5mm at temperatures 50, 60 and 70 ºC and the diffusion coefficient was calculated [6].

A study on the drying kinetics and quality of carrots at different frequency and duration of heating (drying with symmetric and asymmetric heating and cooling periods) in convective dryer was investigated by [4]. Investigated indicators of quality were color change, water activity and β-carotene retention.

The aim of the present study is to obtain some kinetic dependences during drying process of carrots in a laboratory convective dryer combined with microwaves, as well as to investigate the influence of the drying regimes on some quality indicators of the final product.

2 Materials and methods

The subject of this research were carrots of "*Napoli*" variety (*Carrot Napoli*) *Daucus carota L.*

The pre-treatment of the product included washing, cleaning, cutting into discs with a thickness of 4 mm and determination of initial moisture content.

The initial and final moisture content of the product was determined by the weight method, by drying the sample to a constant mass in an atmospheric drying chamber at temperature 100 + 2 °C. A digital scale with accuracy 0.0001 g was used to determine the mass of the material.

The drying process was carried out in a convective dryer combined with microwaves, described in [7]. The product was load on two trays with bulk density 6-8 kg/m² – fig. 1. The two layers were placed one above the other and blown with drying agent in the opposite direction of the gravity field at a flow rate of 3-6 m/s.

The measurement of the weight of the product in the drying process was made by a technical electronic scale with accuracy 0.2 g.

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Fig. 1. Carrots before the drying process

For all experiments, the initial moisture content of the product was 90% w.b. (900 % d.b.), and the final moisture content 9÷16% w.b. (10.4÷18.6 % d.b.).

For each of the experiments, the following quantities were defined [8, 9]:

- *The mass of the wet material:*

$$m = m_0 + m_w, kg \tag{1}$$

where: m - the mass of the wet material, kg;
m_0 - the mass of the absolute dry material, kg;
m_w - the mass of the water content, kg.

- W*et basis* m*oisture content w*:

$$w = \frac{m_w}{m}, (W, \% \, w.b.) \tag{2}$$

- *Dry basis* m*oisture content u*:

$$u = \frac{m_w}{m_0}, (U, \% \, d.b.) \tag{3}$$

The following formula gives a relationship between wet basis and dry basis moisture content of the product:

$$u = \frac{w}{1-w} \tag{4}$$

The following methods were used to evaluate the quality indicators of the dried product:

Total Phenols

The amount of total phenols in the obtained extracts was determined by the *Folin–Ciocalteu's* method. 1 ml of *Folin-Ciocalteu's* reagent (diluted 5 times) and 0.8 ml 7.5% Na_2CO_3 was added to the carrot extract (0.2 ml) [10]. After 20 minutes, the absorbance was measured at 765 nm and was compared with empty sample. Results have been reported as milligram gallic acid equivalents per gram (mg GAE/g d.b.) [11].

Antioxidant activity

DPPH method

The examined extract (0.15 ml) was mixed with 2.85 ml of a freshly prepared solution of DPPH (2,2-diphenyl-1-picrylhydrazyl) (0.1 mM in methanol). The reaction mixture was incubated in the dark for 15 min at 37 °C. The reduction in absorbance was read spectrophotometrically at 517 nm [11].

FRAP method

The reactive was prepared by mixing previously prepared 0.3 M acetate buffer with pH 3.6, 10 mM 2, 4, 6-tripyridyl-s-triazine (TPTZ) and 20 mM $FeCl_3 \times 6H_2O$ in ratio 10:1:1. The examined extract (0.1 ml) was added to 3 ml of FRAP reagent. The reaction mixture was incubated for 5 min at 37 °C in the dark. The absorption of the colored compound formed was measured at a 593nm wavelength [12]. Antioxidant activity results were expressed as mM Trolox equivalents per gram dry raw material (mM TE/g).

Ultrasonic extraction

The ultrasonic extraction was carried out in an ultrasonic bath SIEL UST 5.7-150 (*Gabrovo, Bulgaria*) operating at a frequency of 36 kHz and power 240 W [13]. The extraction was carried out in three centrifuge tubes with a screw and a capacity of 50 ml, in which 5 g of sample were weighed in advance. Ultrasonic extraction was carried out at a temperature of 50 °C for 20 min duration. Each of the extracts obtained was filtered through a paper filter with a pore diameter 0.45 µm. The extraction process was repeated three times, and it was conducted with methanol.

3 Results and discussion

The experimental investigation on drying of carrots were carried out on the laboratory convective dryer combined with microwaves [7] The following drying modes were realized:

- continuous mode – convective heating of the product with blowing the layer with air;
- symmetric intermittent drying regimes 5+5 – microwave heating of the product combined with convective drying with blowing the layer with air;
- asymmetric intermittent drying regimes 1+3 – microwave heating of the product combined with convective drying with blowing the layer with air.

The types of intermittent regimes have been determined by the duration of the heating and cooling periods of the product. By the symmetrical modes 5+5 - equal duration periods of 5 min of heating and 5 min of cooling at 50% microwave power, and for the asymmetrical 1+3 – different duration periods of 1 min of heating and 3 min of cooling at 100% microwave power. Heating was realized in the microwave and cooling - in the drying chamber. [7]

Some kinetic dependencies were obtained during the drying process - the drying curve and the drying rate curve.

The drying curve depicts the change in dry basis moisture content (*u)* of the wet product as a function of drying time (*τ)*.

$$u = f(\tau) \tag{5}$$

The drying rate curve describes the change of the drying rate $du/d\tau$ as a function of dry basis moisture content (*u)* of the dried material - $du/d\tau = f(u)$. These curves can be obtained by graphical differentiation from the drying curves [8, 9].

On fig. 2 the drying curves for the three different regimes are presented. The total drying time *(τ)* was determined – 300 min at combined symmetric intermittent regime 5+5; 200 min at combined asymmetric intermittent regime 1+3 and 170 min at continuous convective regime.

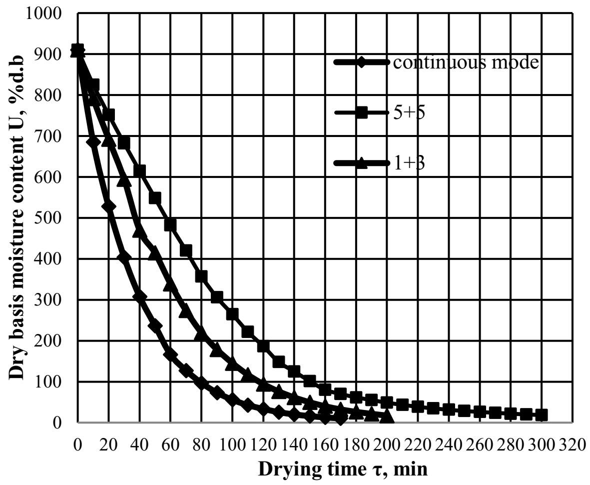

Fig. 2. Drying curves *U=f(τ)* for all investigated regimes

As can be seen from the drying curves, the drying process is the shortest in the continuous convective regime and the longest in the symmetrical intermittent regime (5+5). Despite the fact that the continuous convective regime is the shortest, the energy consumption was significantly greater than the cases of using combined intermittent regimes, which we found in [7]. It is obvious that for the final selection of the method and regime of drying, is necessary also an assessment of the quality of the final product. Better quality can be expected in the intermittent regimes, due to the more frequent cooling of the product, which also leads to its lower average temperature. By intermittent regimes, a distinct (longer) first drying period is also observed, during which the temperature of the products is significantly lower than that of the drying agent.

For each of the investigated regimes, by graphical differentiation from the drying curves, the drying rate curves have been obtained (figures 3-5).

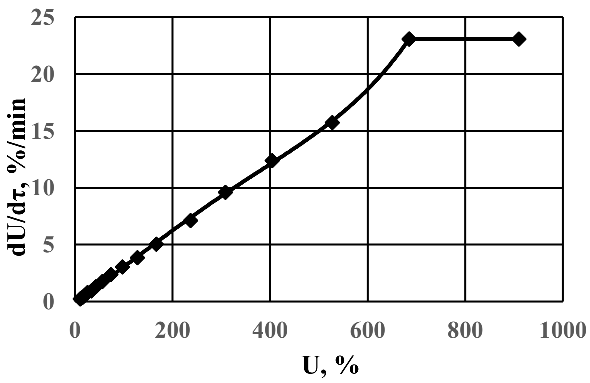

Fig. 3. Drying rate curve in continuous convective regime

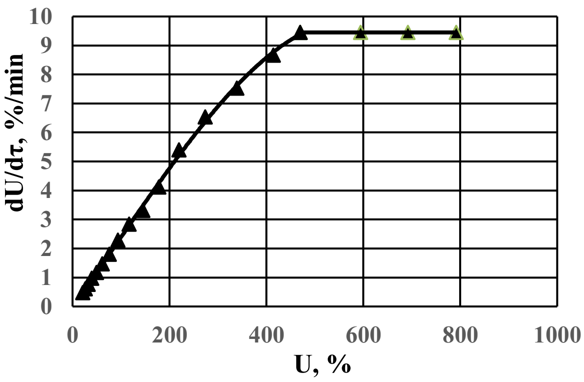

Fig. 4. Drying rate curve in asymmetric intermittent regime 1+3

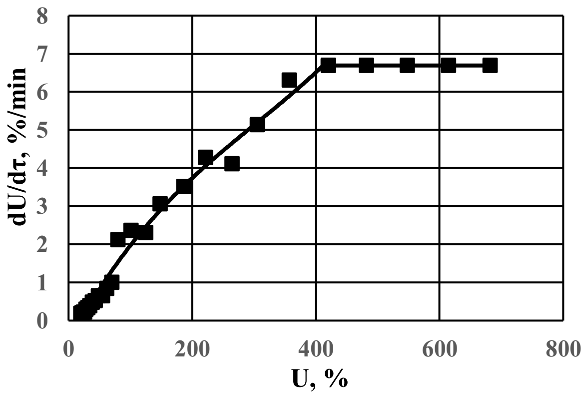

Fig. 5. Drying rate curve in symmetrical intermittent regime 5+5

The differences in the nature of the curves is due to the drying regime. It is clearly seen from the graphs that the drying rate in the first period (period of constant drying rate) is the greatest in continuous convective drying. In this case, the critical dry basis moisture content value is the highest, and most of the drying process takes place during the second period (the period of decreasing drying rate). The listed indicators are completely opposite for the combined symmetric intermittent regime (5+5).

Quality assessment

Fig. 6 shows a general view of carrots after drying.

Fig. 6. Carrots after the drying process.

The initial inspection shows a very good color retention of the product, no signs of burning or non-enzymatic browning, a pleasant characteristic scent and taste.

The influence of intermittent and combined drying regimes on the amount of total phenols and antioxidant activity of carrots was investigated.

Table 1. Amount of total phenols and antioxidant activity.

Samples	Total phenols, mg GAE/g	DPPH, mM TE/g	FRAP mM TE/g
Convective continuous drying at 60 ºC	4.52±0.12	1.40±0.45	1.66±0.05
Combined intermittent asymmetric regime (1+3)	5.03±0.23	2.42±0.01	1.97±0.08
Combined intermittent symmetric regime (5+5)	7.74±0.54	2.15±0.02	3.51±0.53
Fresh product	6.87±0.48	4.24±0.22	2.93±0.24

TE – Trolox equivalents, GAE - gallic acid equivalents.

It can be seen from the values that the highest value of total phenols is observed in the intermittent symmetrical regime (5+5) combined with microwaves, followed by the intermittent asymmetric regime (1+3) and convective continuous drying. It is noteworthy that the value of total phenols in the intermittent symmetrical regime (5+5) is even higher than that in fresh carrots by 11%. A similar increase has been observed by a number of other researchers and has been explained by the mechanism of the transformation of phenol compounds from a non-extractable form to an extractable form [14]. Another possible explanation is that during drying, the production of phenol compounds from their precursors occurred [15]. *Chan et al*. also observed a 38% increase in total phenol content after microwave drying of *Thunbergia laurifolia* leaves compared to fresh leaves. The authors attributed the favorable result to the rapid inactivation of polyphenol oxidase (PPO) activity in the samples upon microwave drying. [16]

Table 2 presents the correlation coefficients between the antioxidant activity assays and total phenol content (TPC).

Table 2. Correlation relationship between total phenols and antioxidant activity.

	DPPH	FRAP
TPC	0.7656	0.9651

The obtained positive correlation give reason to consider that the antioxidant activity of the studied samples of dried carrots is mainly caused by the present phenolic compounds.

4 Conclusion

Drying experiments on carrots in a laboratory convective dryer combined with microwaves at different drying regimes were conducted. Some experimental regularities during drying process have been obtained - drying curves (figure 2) and drying rate curves (figures 3 – 5).

An assessment of the influence of the drying regime on some quality indicators of the final product was made - tables 1 and 2.

The final results obtained give reason to continue research on the influence of the microwave drying process on the quality of food products containing heat-sensitive components.

References

1. M. Berger, T. Küchler, A. Maaßen, M. Busch-Stockfisch, H. Steinhart, Food Chemistry, **106**, 235, (2008)
2. V. Lavelli, B. Zanoni, A. Zaniboni, Food Chemistry, **104**, 1705 (2007)
3. J. Wang, Y.S. Xi, Journal of Food Engineering, **68**, 505 (2005)
4. S. J. Kowalski, J. Szadzińska, J. Łechtańska, Journal of Food Engineering, **118**, 393 (2013)
5. G. Knockaert, A. De Roeck, L. Lemmens, S. V. Buggenhout, M. Hendrickx, A. V. Loey, Food Chemistry, **125**, 903 (2011)
6. A. Arévalo-Pinedo, F. E. X. Murr, Journal of Food Engineering, **80**, 152 (2007)
7. M. Georgieva, D. Atanasov, I. Kiryakov, A. Tashev, M. Nikolova, BIO Web of Conferences **58**, 03003 (2023)
8. V. Elenkov, *Drying and drying equipment*, (Zemizdat, Sofia, 1988) [in Bulgarian]
9. M. Minchev, *Drying equipment*, (UFT Academic Publishing House, Plovdiv, 2012) [in Bulgarian]
10. F.C. Stintzing, K.M. Nerbach, M. Mosshammer, R. Carle, W. Yi, S. Sellappan, C.C. Acoh, R. Bunch, P. Felker, J. Agric Food Chem. **53**, 442 (2005)
11. I. Ivanov, R. Vrancheva, A. Marchev, N. Petkova, I. Aneva, P. Denev, V. Georgiev, At. Pavlov, International Journal of Current Microbiology and Applied Sciences, **3**, 296, (2014)
12. I. Benzie, J. Strain, Analytical Biochemistry, **239**, 70 (1996)
13. N. Petkova, I. Ivanov, P. Denev, A. Pavlov, Turkish Journal of Agricultural and Natural Sciences **1**, 1773 (2014)
14. F. Giusti, E. Capuano, G. Sagratini, N. Pellegrini, Food Chem. **285**, 458 (2019)
15. F. Que, L. Mao, X. Fang, T. Wu, J Food Sci Technol **43**, 1195 (2008)
16. E. W. C. Chan, P. Y. Lye, S. Y. Eng, Y. P. Tan, Free Rad Antioxid **3**, 2 (2013)