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REHYDRATION OF CARROT DRIED USING VARIOUS METHODS

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A b s t r a c t . Raw carrot, blanched and osmotically dehydrated, was dried using three methods: convection, freeze-drying and vacuum-microwave drying. The rehydration was achieved by weighing carrot slices and inundating them with a fixed amount of water at 20ºC. Values of the gain in the mass of the sample, of the relative gain in the water mass, and changes in the relative contents of dry matter were calculated. After five hours of rehydration process only the freeze-dried carrot was characterized by a mass close to the equilibrium mass. At the same time of rehydration, 60% to 80% of the initial water mass infiltrate the carrot tissues. Blanching, and in particular osmotic dewatering, substantially reduce the water absorption rate. No essential impact of the drying method on the value of losses in the dry matter during carrot rehydration was found, for material not subjected to preliminary treatment before drying.

K e y w o r d s : rehydration, drying methods, blanching, osmotic dehydration

INTRODUCTION

Rehydration is a complicated process during which water is absorbed by the plant tissue but, at the same time, there follows an outflow of soluble constituents of dry matter. Drying and preliminary treatment of raw material before the dewatering process produce changes in the nature of chemical compounds and the internal structure of the material, which has a direct impact on the rehydration process (Witrowa-Rajchert 1999). The occurrence of physicochemical changes resulting from the drying of agricultural products is confirmed in the occurrence of various runs of water absorption kinetics and in gain in mass and volume during the rehydration. Theoretically, rehydration is a reverse process to drying. In reality, the product obtained as a result of the drying operation is unable to absorb such an amount of water as it has lost during the dewatering.

Researchers dealing with the rehydration of products having an agricultural origin apply many various indexes to describe the process run. There occurs, however, a high heterogeneity in the nomenclature, which results in a situation that the same magnitude is named in a different way. Lewicki (1998) made a review of the applied indexes and parameters. He also proposed new indexes that, without any ambiguity, allow evaluating the degree of damage to the tissues of biological material basing on the rehydration process run. Water absorption capacity (WAC) and dry matter holding capacity (DHC) are indexes that adopt values ranging: $0 \leq WAC;DHC \leq 1$. He calls the product of both the indexes the rehydration ability and interprets it as follows: the lower the index value, the higher the degree of damage to the tissues.

Osmotic dewatering is a preliminary operation aimed at the reduction of moisture content in a material intended for further processing (e.g. drying) and at improving the quality of dried material. In order to strengthen the interference of osmotic dewatering with the material, accompanying operations are used, e.g. exposure to gamma rays (Nayak *et al.* 2006). The combined action of both the operations reduced the water absorption capacity of carrot and increased the losses in dry matter in relation to the control sample. The osmotic stress produced in the cells of carrot subjected to the dewatering process lowered the permeability of cellular walls, which engendered a drop in the absorptive capacities during the rehydration process.

As a result of osmotic dewatering also the size and shape of parenchyma cells change, producing changes in the size of intercellular spaces, which was evidenced on the example of an apple by Lewicki *et al.* (2005). Contact with an osmoactive active solution reduced the hydrostatic pressure inside the cell and produced the formation of expanding forces. The extension of the osmotic interference time with apples up to 3 hours produced the separation of cells and the formation of small intercellular spaces, which was the cause of discontinuity of the tissue structure.

Lewicki *et al.* (1997) examined the rehydration of apples sliced into cubes and dried by convection. They observed a drop in the sample height at the first stage of the rehydration process; upon reaching the minimum value a swelling of the sample followed. Collapse of the structure, occurring at the first rehydration stage, was due to the plasticization of the glassy matrix by water.

Krokida *et al.* (2003) and Femenia *et al.* (2000) examined the impact of the temperature of water used for rehydration on the process run. They obtained contradictory results, perhaps because the latter applied to different plant raw material. Krokida *et al.* (2003) noticed an improvement of rehydration kinetics of a series of fruits and vegetables along with water temperature rise. Femenia *et al.* (2000) found a drop in the sorptive properties of broccoli along with distilled water rise. Broccoli absorbed water most intensively at 20-40°C.

Bastard *et al.* (2001) discovered a significant impact of broccoli storage time and temperature on water sorption capacity (WSC). The highest value of WSC is characteristic for broccoli stored at 5°C, whereas the lowest value of WSC is characteristic for samples stored at 40°C. The extension of the broccoli storage time produced a reduction in the value of water sorption capacity. The worsening of the product quality along with the rise in the storage time and temperature were associated with a significant rise in the degradation of cellular walls.

Mastrocola *et al.* (1997) conducted rehydration of freeze-dried strawberries in a sugar solution. They found that by changing the solution concentration and the dehydration duration a series of product features changed significantly, e.g. water activity. Such a method of modifying the product quality may determine its use, e.g. for frozen ice-cream desserts.

Marabi *et al.* (2006) investigated the impact of the drying method and the rehydration time for dried mass from carrot on the sensory properties of the product. The samples were dried by convection and vacuum-puffed using standard methods in the preparation of products that were constituents of instant soups. The rehydration time had the most significant influence on the decision to approve a product obtained with the convection method since the samples were characterized by high heterogeneity of physical features, especially hardness, and a reduced water absorption capacity during the rehydration process.

Giri *et al.* (2007) compared the rehydration properties of mushrooms dried by vacuum-microwave and convection. Decidedly better reconstitution properties are shown by mushrooms dried by vacuum-microwave method in relation to mushrooms dried by convection. Mushrooms dried by vacuum-microwave are rehydrated quicker and absorb more water. Those relationships were confirmed after changing the power of microwaves and at a different pressure prevailing in the chamber and after changing the temperature of air during the convection drying.

Both the freeze-drying and the vacuum-microwave drying belong to the group of modern drying methods to which great expectations are attached in order to obtain high quality of dried products. Simultaneously, for both the methods, the theoretical rudiments of the process have been well recognized (Kramkowski 1998, Szarycz 2001), which creates a potential for precise anticipation of the dewatering process run.

The majority of dried products are intended for further processing or consumption, however, after previous rehydration. Therefore, research work covering the characteristics of the product after the rehydration process is so essential.

The aim of this paper is to describe the impact of the drying method as well as the blanching process and osmotic dewatering as preliminary operations on the basic parameters that characterize the rehydration process of carrot root.

MATERIALS AND METHODS

The impact of the drying method on the rehydration of dried mass was investigated for a popular root vegetable, carrot. Samples were prepared in the form of cylinders of a height amounting to 5 mm and a diameter equal to 20 mm. The dried material not subjected to preliminary treatment as well as blanched and osmotically dewatered was dried. Blanching was performed in water at 95°C ± 2°C for 3 minutes. The content of dry matter in the raw material was 12.7% and was reduced, after blanching, to 10.5%. A 5% NaCl solution was used for the osmotic dehydration. The dewatering duration was 24 hours. A drop in the carrot moisture contents from 88% down to 79% was obtained. Convection drying was performed in a laboratory drier at a drying agent temperature of 50°C and an air flow rate of 1.5 m s^{-1}. The system had six individually controlled stands with heating elements of 2 kW maximum power. The drier type OE-950 was used for the freeze-drying. The samples were frozen at a temperature of –20°C at the rate of 1°C min^{-1}. The following drying parameters were used: heating plate temperature (20°C), pressure in the drying chamber (100 Pa), contact method of heat delivery. Microwave drying was performed in a vacuum-microwave drier with amplitude control of magnetrons. The power of the magnetrons was set at a level of 40% of their maximum power, i.e. 480 W. The pressure in the drying chamber was maintained within the range from 4 to 10 kPa.

The rehydration was achieved by weighing 3 carrot slices each and, upon placing them in a beaker, by inundating them with a fixed amount of water at 20°C. The determination was done in three repetitions. The rehydration kinetics was tested for 5 hours by taking samples after 0.5; 1; 2; 3; 4 and 5 hours of the process duration. Before weighing, the samples were filtered of water on a sieve and dried with blotting paper. In order to determine the content of dry matter in the carrot after individual rehydration stages, the samples were dried at 65°C for 48 hours in a KC 100/200 laboratory drier. The weight of the samples was determined using a WPE 60 balance. Statistically significant differences in the impact of the drying method on the values of individual indexes that characterize the hydration of carrot were demonstrated by studying the run of kinetic equations in the time interval covering the whole experiment. To this aim, the values of the standard error of estimation (SE) were used. Confidence curves were plotted on the diagrams $y(\tau) = \hat{y}(\tau) \pm 2\mathrm{SE}$, where $\hat{y}(\tau)$ designate the forecast of the index value at the moment τ as obtained from the kinetic equations. The disjunction of confidence intervals was the basis to conclude on the statistically significant difference between the curves.

RESULTS AND DISCUSSION

If the drying process did not produce destructive changes to the carrot tissue structure, then, after the rehydration, the material should reach the mass it had before the drying. The gain in the mass of the sample during the rehydration process as related to the initial mass allows calculating the value of the relative gain in mass. For the description, following Witrowa-Rajchert (1999), the formula was proposed in the form:

$$m_{\tau} \cdot m_0^{-1} = a + b[1 - 1(1 + b \cdot c \cdot \tau)^{-1}] \quad (1)$$

where: m_{τ} – mass of the sample after time τ of the rehydration process, m_0 – initial mass of the sample.

Drying produces a reduction in the water absorption and maintenance capacity in the plant tissue. The larger the changes occurring in the tissue, the less amount of water can it absorb during the rehydration. The values of the relative gain in water mass were calculated as a quotient of the water mass absorbed by carrot during the rehydration process in relation to the water mass in the raw material. Equation (1) was used for the description.

During the rehydration there follows a loss in soluble constituents of the dry matter of the rehydrated material that depends mainly on the chemical composition and the structure of tissues. The changes in the relative contents of dry substance during the rehydration were calculated as a quotient of the dry mass of the sample after a definite rehydration time as related to the dry mass of the sample before the rehydration. For the description, following Witrowa-Rajchert (1999), a solution in the following form was suggested:

$$m_{s\tau} \cdot m_{s0}^{-1} = a + [b(1 + b \cdot c \cdot \tau)^{-1}] \quad (2)$$

where: $m_{s\tau}$ – dry mass of the sample after time τ of the rehydration, m_{s0} – dry mass of the sample before the rehydration.

Basing on the equations, the equilibrium values of individual indexes, estimation standard errors and determination coefficients were calculated, Table 1.

The relative gain in the sample mass in relation to the initial mass of the rehydrated dried mass for carrot dried using three methods is presented in Figures 1-3. The highest gain in the sample mass was recorded for carrot blanched before the drying, for which the mass after five hours of the rehydration process increased almost seven-fold. In the same time, there followed only a 4.5-fold gain in the mass of osmotically dehydrated samples and a 5-fold gain in the mass of the rehydrated dried mass originating from carrot not subjected to preliminary operations. When studying the equilibrium values and the accuracies of their determination one can state that after five hours of the rehydration process the freeze-dried carrot is characterized by a mass close to the equilibrium mass. The carrot not subjected to a preliminary treatment before the freeze-drying (Fig. 1) reaches its equilibrium mass as early as after 0.5 hour of rehydration. The nature of the run of the kinetic equations adopted for the description of the gain in the sample mass allows stating the carrot dried by vacuum-microwave method has the highest potential capacity for the gain in sample mass, however, this would require a considerable extension of the rehydration duration. The equilibrium values of relative gain in the mass of the carrot dried by vacuum-microwave are 10% higher than the equilibrium values obtained for the carrot dried by convection (excluding the samples dewatered osmotically) and 20% to 30% higher than the equilibrium values for the freeze-dried carrot.

Table 1. Relative gain of sample mass, water mass and loss of dry matter during carrot rehydration

Pre-treatment		Gain in sample mass			Gain in water mass			Loss of dry matter mass		
		I	II	III	I	II	III	I	II	III
Convective	without pre-treatment	5.51	0.19	0.982	0.89	0.03	0.985	0.31	0.02	0.992
	blanching	7.90	0.28	0.979	0.95	0.04	0.980	0.38	0.02	0.989
	osmotic dewatering	5.30	0.20	0.977	0.82	0.03	0.980	0.27	0.02	0.990
Vacuum-microwave	without pre-treatment	6.19	0.30	0.964	0.84	0.05	0.967	0.29	0.04	0.971
	blanching	8.68	0.25	0.987	0.86	0.03	0.986	0.37	0.03	0.983
	osmotic dewatering	5.17	0.08	0.996	0.72	0.01	0.996	0.31	0.02	0.989
Freeze-drying	without pre-treatment	5.12	0.12	0.994	0.72	0.02	0.995	0.33	0.02	0.989
	blanching	6.58	0.16	0.994	0.69	0.02	0.995	0.37	0.02	0.984
	osmotic dewatering	4.45	0.10	0.993	0.66	0.02	0.993	0.29	0.02	0.989

I – equilibrium value,
II – standard error,
III – coefficient of determination r^2.

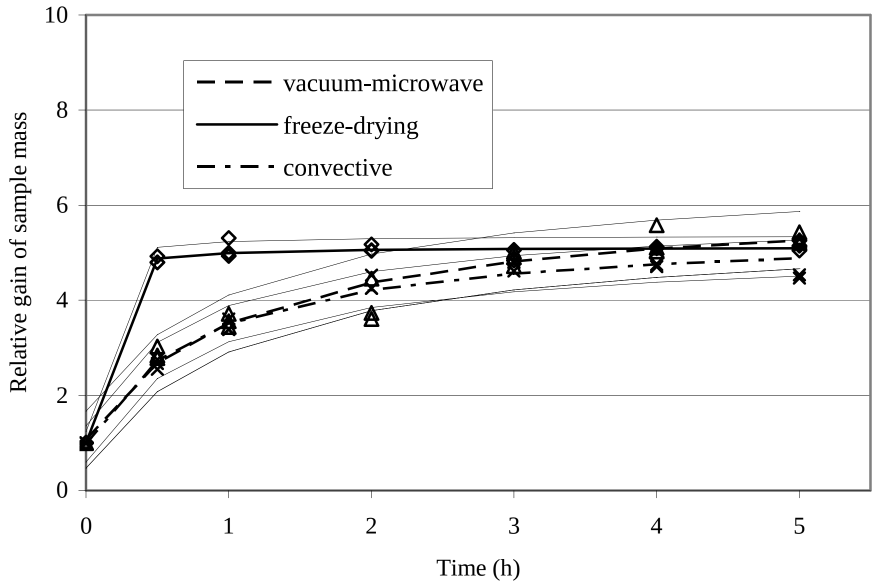

Fig. 1. Relative gain of sample mass for carrot not subjected to preliminary treatment

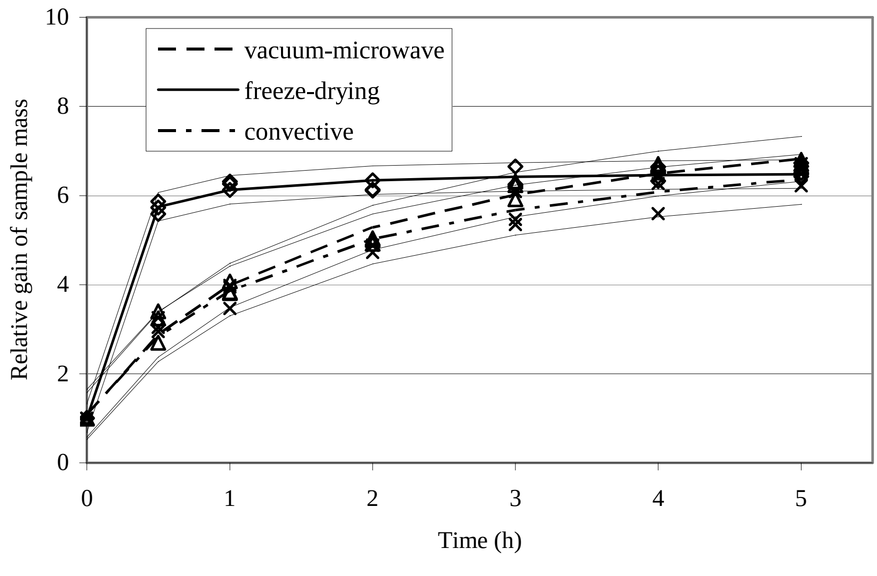

Fig. 2. Relative gain of sample mass for carrot blanched before drying

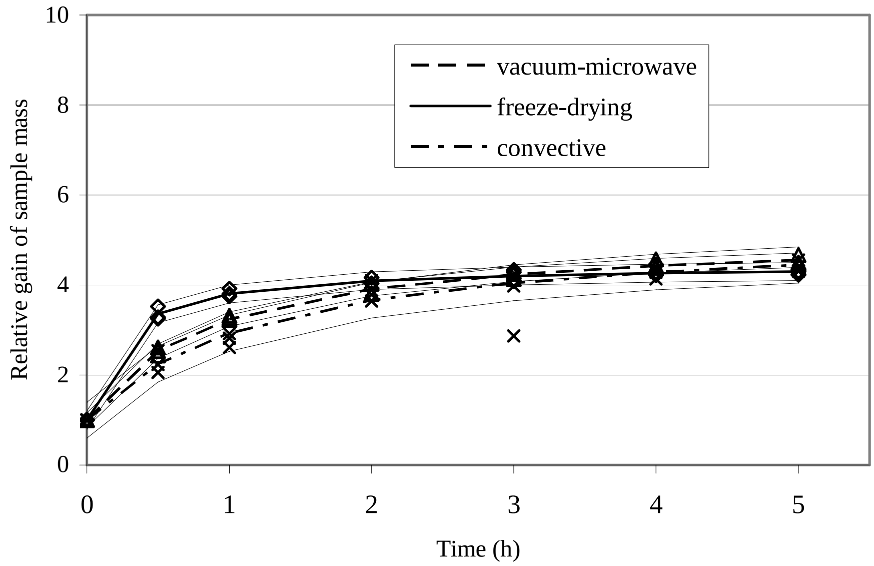

Fig. 3. Relative gain of sample mass for carrot osmotically dehydrated before drying

The amount of water absorbed by carrot during the rehydration process in relation to the mass of water in the raw material is presented in Figures 4-6. After five hours of carrot rehydration, 60% to 80% of the initial water mass infiltrate the tissues. Only the product obtained as a result of freeze-drying, after the pre-set rehydration time, absorbed an amount of water close to the equilibrium value. The water absorption kinetics also is the highest for the freeze-dried carrot whereby the blanching and, in particular, osmotic dewatering substantially reduce the process run dynamics. The carrot dried by convection has the highest water absorption capacity, the carrot dried by vacuum-microwave has a slightly lower water absorption capacity, and the freeze-dried carrot has decidedly the lowest capacity to absorb water, which results from the nature of the run of the mathematical equation adopted for the description.

The loss in soluble constituents of dry matter during carrot rehydration is presented in Figures 7-9. After five hours of carrot rehydration, about 50% to 70% of the dry matter contained in the dried mass diffuse from the tissue to the solution. Such high losses are due to the bursting of cytoplasmic membranes as a result of which the constituents of the cytoplasmic solution flow to the surrounding water. The drying of plant tissue produces shrinkage and stiffening of the cytoplasmic membrane which, during the rehydration, is unable to restitute its initial properties. If the dewatering lasted infinitely long, the least losses in dry matter (62-63%) would follow for the blanched carrot. The losses in dry matter for the carrot osmotically dewatered and not subjected to preliminary treatment are higher and total 67% to 73%. Lower losses noted for the carrot blanched before drying result from the fact that already during the blanching process itself ca. 11% of soluble constituents diffuse from the carrot. During the first two hours of the rehydration of blanched and osmotically dehydrated carrot before the convection drying, essentially more dry matter diffuses to the solution in relation to the dried mass obtained by the sublimation method. Analysis of the longer rehydration time and the equilibrium values allows stating that within the area of individual preliminary operations no essential impact of the drying method on the value of losses in dry matter during carrot rehydration was found.

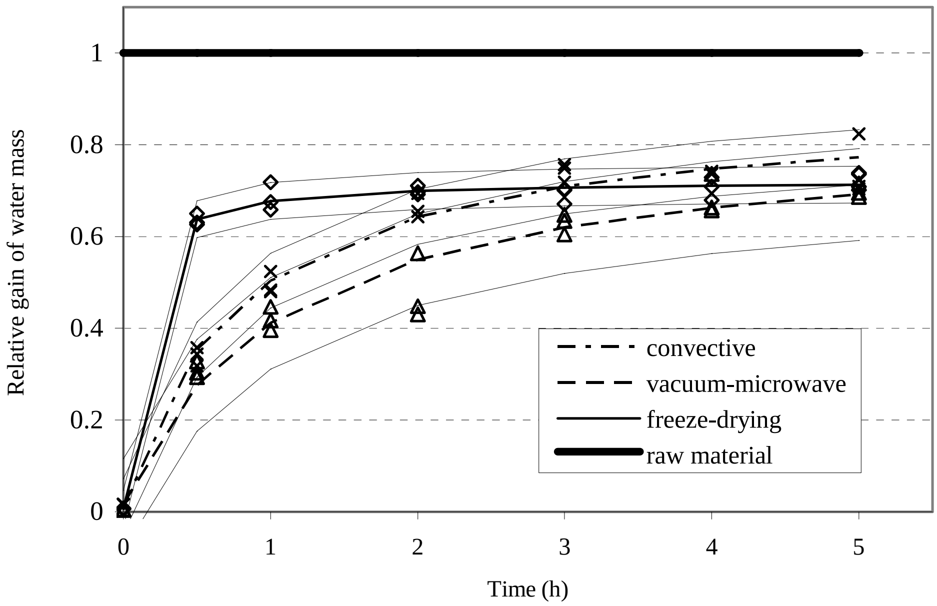

Fig. 4. Relative gain of water mass for carrot not subjected to preliminary treatment

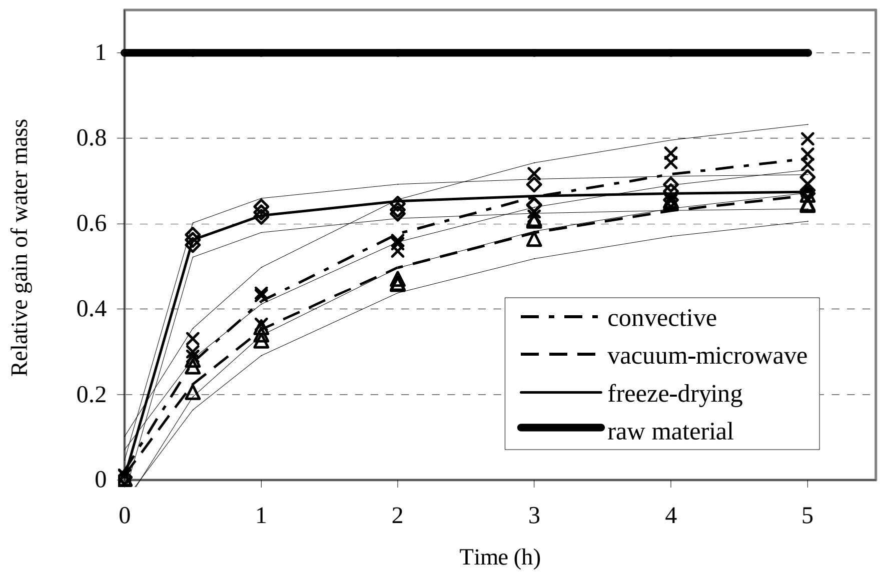

Fig. 5. Relative gain of water mass for carrot blanched before drying

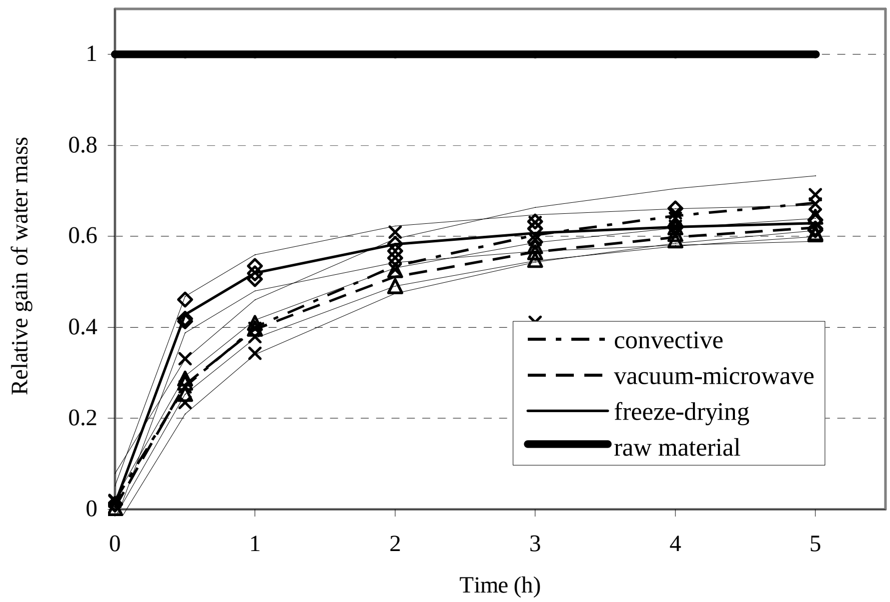

Fig. 6. Relative gain of water mass for carrot osmotically dehydrated before drying

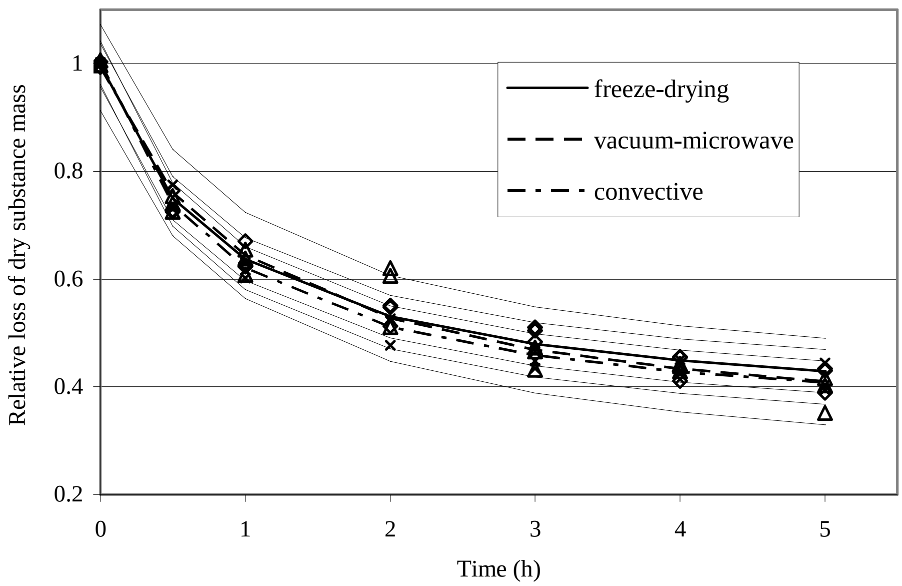

Fig. 7. Relative loss of dry matter mass for carrot not subjected to preliminary treatment

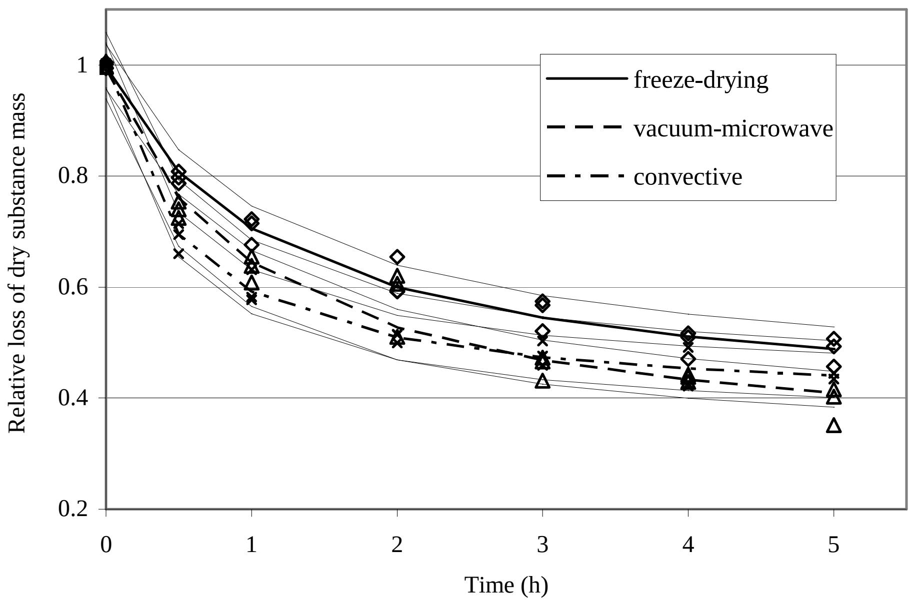

Fig. 8. Relative loss of dry matter mass for carrot blanched before drying

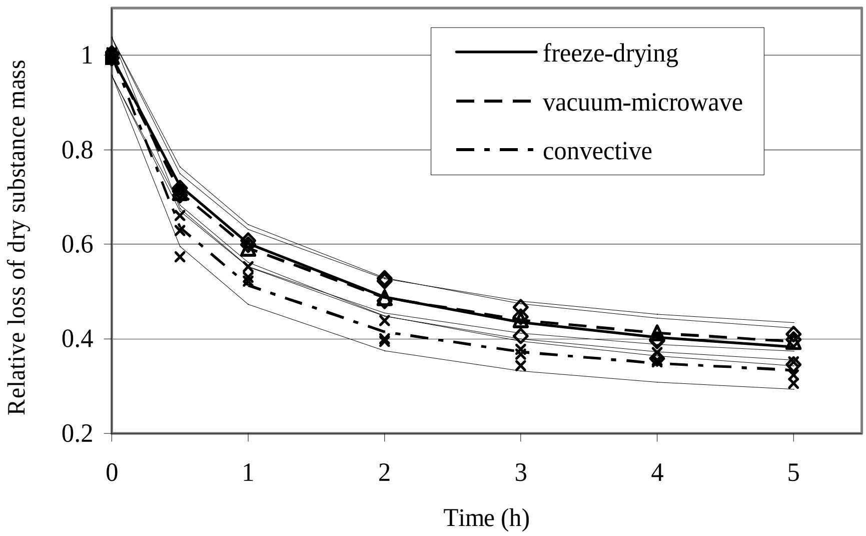

Fig. 9. Relative loss of dry matter mass for carrot osmotically dehydrated before drying

CONCLUSIONS

1. The highest ability for gain in the sample mass during the rehydration process is characteristic for the freeze-dried carrot. As soon as after 2 hours of the rehydration the samples reach their equilibrium mass for all the versions of the preliminary operations. The highest potential capacity for gain in the sample mass is demonstrated by the carrot dried by vacuum-microwaves; it is 20% to 30% higher than the equilibrium values reached by the freeze-dried samples, which results from the nature of the equations adopted for the description of the process run.

2. After 5 hours of the rehydration, 60% to 80% of the initial mass of water infiltrate the carrot tissues. Blanching, and especially osmotic dewatering, subpstantially decrease the water absorption dynamics in relation to the carrot that has not been subjected to preliminary treatment. After an infinitely long time of rehydration the highest amount of water can be absorbed by the convection-dried carrot, less by the carrot dried by vacuum-microwave and decidedly the least by the freeze-dried carrot.

3. Depending on the preliminary treatment and the drying method applied, 50% to 70% of dry matter contained in the dried material diffuse from the carrot tissue to the solution during the rehydration. For a rehydration process lasting more than 2 hours, within the area of individual preliminary operations the drying method has no substantial effect on losses in the soluble constituents of the dry mass of the carrot being rehydrated.

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REHYDRACJA MARCHWI SUSZONEJ RÓŻNYMI METODAMI

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Streszczenie. Marchew blanszowaną, odwodnioną osmotycznie i nie poddaną obróbce wstępnej suszono trzema metodami: konwekcyjnie, sublimacyjnie i mikrofalowo pod obniżonym ciśnieniem. Próbki w kształcie walca rehydrowano w wodzie o temperaturze 20ºC. Obliczono wartości przyrostu masy próbki w trakcie uwadniania, wartości względnego przyrostu masy wody oraz ubytki suchej substancji. Po pięciu godzinach rehydracji tylko próbki marchwi suszonej sublimacyjnie charakteryzują się masą zbliżoną do masy równowagowej. W tym samym czasie, od 60% do 80% początkowej zawartości wody wnika do tkanek marchwi. Blanszowanie, a szczególnie odwadnianie osmotyczne, istotnie zmniejsza szybkość wchłaniania wody. Nie stwierdzono istotnego wpływu metody suszenia na ubytki rozpuszczalnych składników suchej substancji w trakcie uwadniania marchwi, której nie poddano zabiegom wstępnym.

Słowa kluczowe: rehydracja, metody suszenia, blanszowanie, odwadnianie osmotyczne