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Drying of Osmotically Dehydrated Biological Materials

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Abstract: This paper concerns convective drying of biological materials with osmotic dehydration pretreatment. The main aim of the studies was to work out an efficient conditions of such a combined drying and to determine the amount of water which can be removed from the products due to immersion in the hypertonic aqueous solutions of sucrose, fructose, glucose at three different concentrations (20, 40 and 60%). The carrot samples were used as the experimental material. The samples dehydrated with osmotic solutions underwent further convective drying. The quality of products was assessed on the basis of visual appearance and with using the colorimetric measurements. It was found that the preliminary osmotic dehydration positively influences the final product quality.
Key words: Convective drying, osmotic dehydration, carrots, drying kinetics, product quality

INTRODUCTION

It is known that fresh fruits and vegetables constitute an important source of valuable nutrient substances such as vitamins, minerals, cellulose and others. Unfortunately, fresh fruits and vegetables cannot be stored for a long time. High moisture content (>80%) and water activity are favorable for development of germs and putrefactive bacteria responsible for decaying processes.

Drying is one of the most often applied industrial method for preservation of nutrient components of post harvested vegetables and fruits. The main purpose of this operation is a reduction of water content in these products, and thus a stabilization and prolongation of the nutritive values for longer storage and utilization. Thanks to dewatering and drying the weight and volume of these products is diminished, and thus the packaging and transportation costs are reduced, which is another benefit of drying operation (Mujumdar and Law, 2010; Sagar and Suresh 2010).

However, drying may cause also a undesirable deterioration of products quality. High temperature and long time of drying often change the shape, color, taste, aroma and nutrient properties of fruits and vegetables (Korkida et. al 1998, Markowski et. al 2006, Santos and Silva 2008, Vázquez-Vila et al. 2009). Besides, drying is also one of the most energy-intensive unit operation in food industry. It has been stated that drying accounts for up to 15 % of all industrial energy usage (Mujumdar and Passos, 2000; Chua et al., 2001; Kudra, 2004). Therefore, alternative methods of drying are sought to minimize the energy consumption and improve the final product quality (Min et. al).

Osmotic dehydration (OD) is a method that can improve the drying efficiency of fruits and vegetables. It is a non-thermal process which utilize osmosis phenomenon occurring after immersion of plant tissue in hypertonic aqueous solution. Difference between water activity and osmotic pressure in plant tissue and ambient hypertonic solution generates two oppositely directed fluxes. Water is permeated through the cell membrane from plant tissue to hypertonic solution, meanwhile the solute solids penetrates the cell from ambient solution (Pan et. al, 2006). In this way even 50 % of water initially presented in the material can be removed at a relatively low expenditure of energy.

As it has been stated in the respective literature (Lewicki and Lenart, 2006), a convective drying needs about 5 MJ per kilogram of evaporated water, compared to 0.1-2.4 MJ per kilogram of water removed in osmotic dehydration. It has been also stated that quality of dried products, initially dehydrated with osmotic solution is much better than that without OD pre-treatment (Konopacka et. al 2009, Kowalski et. al 2009, Maftoonazad 2010).

Additionally, OD contributes to reduction of the total energy consumption as well as to shortening of drying time and to lowering the process temperature. As the products after OD require furtherer drying to attain a desirable moisture content, OD is very often used as a pretreatment process before the main drying operation (air, vacuum, microwave, etc).

The aim of this study is to investigate the influence of osmotic agent type and the solution concentration on the kinetics of OD and the final product quality after air drying. Three types of osmotic agents (sucrose, fructose, glucose) at three solution concentrations (20, 40 and 60%) were examined. Carrot was used as the experimental material. Quality of products was assessed on the basis of visual appearance of the sample and with using the colorimetric measurements.

MATERIAL and METHOD

Sample preparation

The fresh carrots (*Daucus carota* L.) from the local market were used as the experimental material. Each root of carrot was washed, cleaned and peeled. Next, the rectangular samples of dimension 40×30×5 mm (length × width × thickness) having approximately similar weight (8 g) were prepared with a ceramic knife.

Dehydration process

Osmotic dewatering processes with using the aqueous solutions of sucrose (SUC), fructose (FRU) and glucose (GLU) in three concentrations of 20%, 40% and 60% were analyzed. The solutions were prepared in a room temperature (21°C) by mixing (for 10 min) the suitable mass of osmotic agent with the distilled water. The ratio of solution to sample mass was 25:1 to avoid dilution effect. A given volume (200 mL) of such a prepared solution was poured into a transparent container (capacity 750 mL). Next, the sample was immersed in the solution and the container was closed with hubcap to prevent water evaporation. Dewatering process lasted 6 hours. Changes of the sample mass were measured with accuracy of 0.01 g with the use of the balance model AJH-2200CE produced by VIBRA after 1.5, 3 and 6 hours of the osmotic process. After finishing the OD each sample was convectively dried-up in the laboratory dryer (Fig. 1).

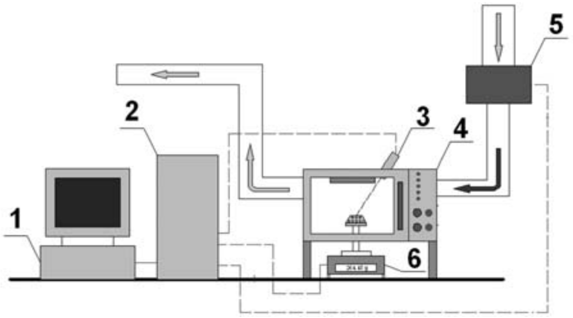

Figure 1. Scheme of hybrid dryer:

1-computer, 2-programmer, 3-pyrometer, 4-dryer chamber, 5-air heating system, 6-balance.

Convective drying

The osmotically dewatered sample was dried convectively with the airflow velocity v = 1.2 m/s and air temperature T = 55 ºC. Air relative humidity (*RH*) was not set manually or controlled, but was measured in each drying test (*RH* = 21 % on average).

The balance (6), type WPS 2100/C/1 (precision 0.01 g) produced by Radwag (Poland), was used for the measurement of the sample mass reduction. The temperature of the sample surface was measured by the pyrometer (3), model MI (precision 1ºC), produced by Raytek (USA). All the mentioned parameters (sample mass, temperatures, etc.) were recorded during the whole process and stored in the standard personal computer (1).

Assessment of product quality

Each sample was photographed before OD, after OD, and after drying process for visual assessment of its quality. Color of the sample surface was measured before and after OD as well as after drying with the

Konica Minolta CR400 colorimeter (D65 illuminant, 2° observer) and expressed in CIELab color space (precision 0.01). Before measurement the colorimeter was calibrated with a special white plate. Each measurement was carried out on a white ceramic plate to provide identical measure conditions and eliminate the background influence. Two spots for color measurement were randomly chosen on each sample and in each spot ten measurements of color parameters (*L**, *a**, *b**) were done. Next, the arithmetic mean was calculated. On the basis of obtained results, the differences in samples color (before and after drying) were assigned as a relative color change parameter ΔE (1).

$$\Delta E = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \qquad (1)$$

The another relative color change parameter $\Delta E00$ was evaluated in Konica Minolta Color Data Software – SpectraMagic NX–CMs–100W (ver. 1.9). This parameter is much more comprehensive and takes into account imperfection of human eye in color perception and other factors which affect the color measurements.

Determination of process parameters

Initial moisture content (MC_i) of the material was determined with the moisture analyzer model XM120 (precision 0.01 %), produced by Precisa (Switzerland).

The mass of dry matter after OD differ from that before OD, and the difference is termed "solid gain". The solid gain (*SG*) and water lose (*WL*) are evaluated in compliance with equations (2) and (3) (Pan et al. 2003):

$$SG = \frac{s_t - s_i}{m_i} \qquad (2)$$

$$WL = \frac{(m_i - m_t) + (s_t - s_i)}{m_i} \qquad (3)$$

where s_t is the mass of dry matter after OD process, s_i is the initial mass of dry matter (before OD process), m_i is the initial mass of sample and m_t is the mass of sample after OD process.

Masses of the dry matter (s_t and s_i) were determined after 24-hrs drying at T = 75°C in convective dryer, model SML42/250/M, produced by Zalmed (Poland).

RESULTS and DISCUSSION

Kinetics of osmotic dehydration (OD)

Figure 2 presents the plot of moisture content (*MC*) versus time (*t*) for 3 different osmotic agents in three different concentrations.

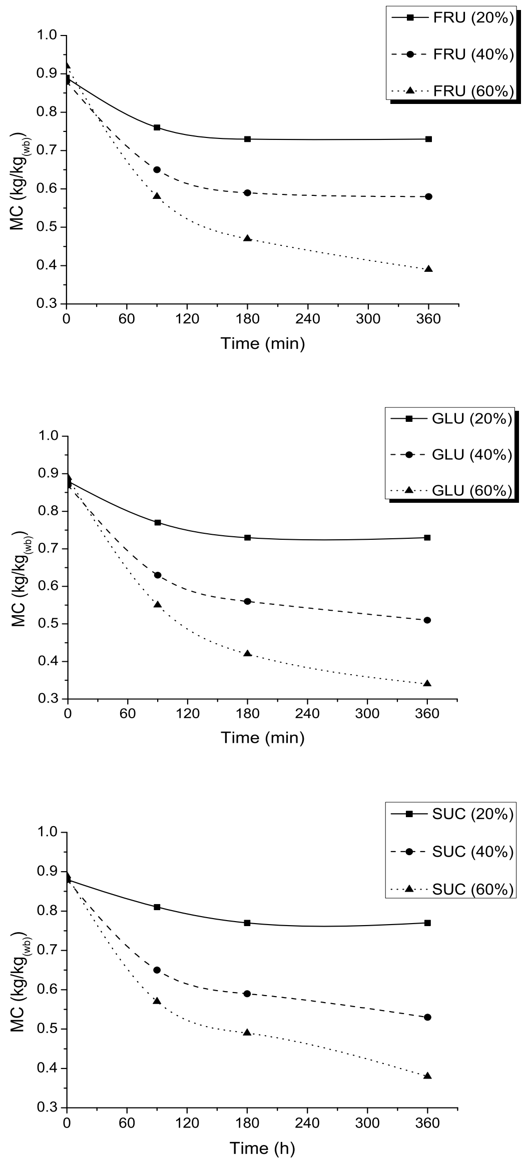

Figure 2. Kinetics of osmotic dewatering process.

It can be easily noticed that the concentration of hypertonic solution has a decisive influence on the kinetics of osmotic dehydration (OD). In each case the volume of removed water and the rate of process depend on the concentration of the solution. Obviously, the final moisture content (*MC_f*) diminishes with an increase of osmotic solution concentration, however, the time of OD for greater concentrations was not sufficient to reach the equilibrium state between the solution and the dehydrating body. Curves for 40% (except fructose) and for 60 % solutions have distinctly falling tendency, while those for all 20 % (and for 40% fructose) solutions attained stable equilibrium level after 360 min dehydration.

The most important OD parameters are presented in Table 1. The analysis of the data given in Table 1 allows to state that the type of the osmotic agent used in this studies has an insignificant influence on dewatering, effect of the carrot. Every assigned parameter such as *MC_{fi}* water lose (*WL*) and solid gain (*SG*) differentiate not more than 0.05 $g/g_{(wb)}$ for each type of solution and given concentration.

However, the concentration has the decisive influence on each of the mentioned parameters. The higher concentration is used, the bigger amount of water is removed from the carrot sample, but also more solute solid penetrate the carrot cells. *SG* varied between 0.02 $g/g_{(wb)}$ (SUC) and 0.04 $g/g_{(wb)}$ (FRU) for 20% solutions, while for 60% solutions *SG* achieved the level 0.11 $g/g_{(wb)}$ (GLU) and 0.17 (FRU) $g/g_{(wb)}$. The changes of *WL* were more distinct and for 20% solutions *WL* was 0.15 $g/g_{(wb)}$ on average but for more concentrated solution rised even to 0.58 $g/g_{(wb)}$ (GLU).

The maximal rate of osmotic dehydration (*ODR_{max}*), measured at 90-th minute of the dewatering process, depend both on the solution concentration and on the type of osmotic agent. The highest *ODR_{max}* value was obtained for 60% solution of glucose (2.38×10^{-2} g/min) whereas the lowest for 20% sucrose solution (4.33×10^{-3} g/min). It was also observed that the dewatering of carrot with the use of sucrose solutions is evidently slower than by application of fructose or glucose solution.

Kinetics of air drying

Figure 3 presents the drying curves of the fresh and the OD samples. The convective drying (CV) of fresh samples was carried out to visualize the influence of the OD pre-treatment on the drying time of carrot. For the OD samples with sucrose solutions, the time of CV drying was very similar or even longer in comparison to not OD samples (340 and 350-360 min respectively). Difference between the results follows from the crystallization of substances on the sample surface. The sugar settled on the sample surface and blocked the moisture outflow. This is possibly the main reason for the drying time lengthen and increasing of *MC_f* with respect to that in pure convective drying.

Table 1. Osmotic dewatering parameters.

Osmotic Agent	Cp (%)	SG ($kg/kg_{(wb)}$)	WL ($kg/kg_{(wb)}$)	ODR_{max} (g/min)
Glucose	20	$0.03\pm2.92\times10^{-3}$	$0.16\pm3.98\times10^{-3}$	7.39×10^{-3}
	40	$0.08\pm2.82\times10^{-3}$	$0.32\pm3.70\times10^{-3}$	1.49×10^{-2}
	60	$0.11\pm2.80\times10^{-3}$	$0.58\pm3.51\times10^{-3}$	2.38×10^{-2}
Fructose	20	$0.04\pm2.81\times10^{-3}$	$0.17\pm3.82\times10^{-3}$	8.06×10^{-3}
	40	$0.09\pm2.78\times10^{-3}$	$0.29\pm3.68\times10^{-3}$	1.22×10^{-2}
	60	$0.17\pm2.77\times10^{-3}$	$0.56\pm3.48\times10^{-3}$	1.96×10^{-2}
Sucrose	20	$0.02\pm2.65\times10^{-3}$	$0.1\pm3.65\times10^{-3}$	4.33×10^{-3}
	40	$0.13\pm2.84\times10^{-3}$	$0.34\pm3.70\times10^{-3}$	8.94×10^{-3}
	60	$0.14\pm2.79\times10^{-3}$	$0.48\pm3.55\times10^{-3}$	1.77×10^{-2}

Cp – concentration; SG – solid gain; WL – water lose; ODR_{max} – maximal osmotic dehydration rate

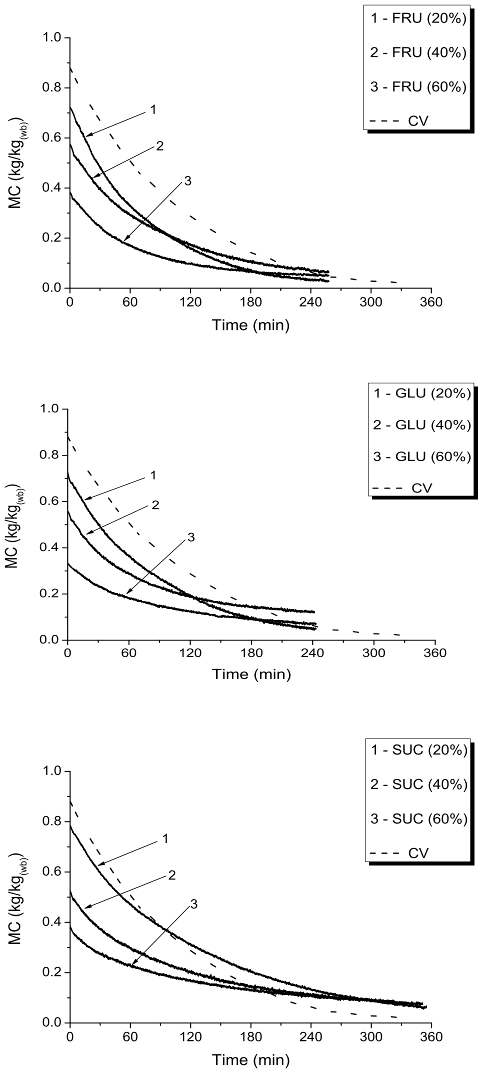

Figure 3. Kinetics of convective drying

Quality of the samples

Figure 4 presents photos of the samples dehydrated with sucrose solutions.

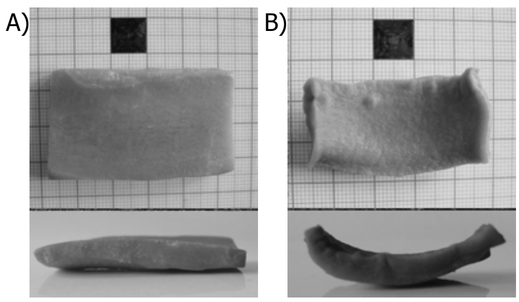

Figure 4. Photos of sample dewatered with sucrose solution: A) 20%, B) 60%

As it is seen the OD causes a sample deformation. The range of this deformations depends on the concentration and type of solution. The samples dewatered with 20% sucrose solution looks similarly as the fresh ones. The deformation is insignificant, the color and texture of the samples changed to a lesser degree. Whereas the samples dehydrated with 60% solution of sucrose look absolutely different. They are deformed significantly, the color and texture of samples differ distinctly from the fresh ones. The photos of samples dehydrated with sucrose solution are chosen to shown the most distinguishable final sample appearance. Samples dehydrated in fructose or glucose solution were not deformed to such visible degree.

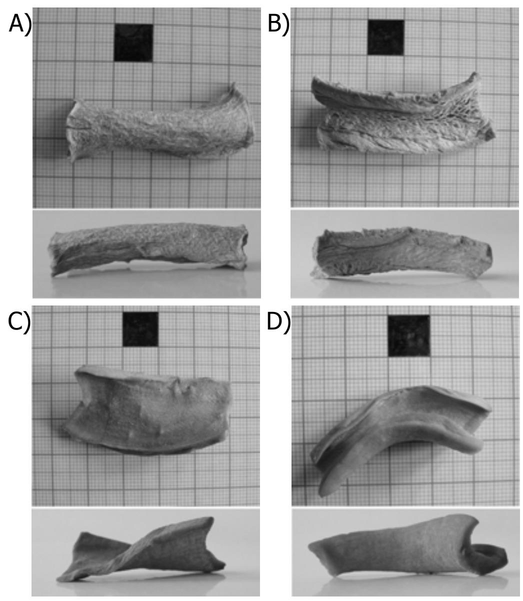

Figure 5. Photos of sample after CV drying: A) fresh, B) FRU 20%, C) GLU 40%, D) SUC 60%

The photos of fresh and dehydrated samples after convective drying are presented in figure 5. The quality of carrot after pure convective drying is very bad. The samples are deformed, their surface became hard, rough and shrunk, and initial color is lost. The samples initially dehydrated with the hypertonic solutions look much better. Although, the shape of these samples do not differentiate significantly from the others, however, the color and texture are much better in comparison to those without OD pretreatment.

The relative color parameters (ΔE, $\Delta E00$) are presented for the individual process in Table 2. These parameters indicate the differences between colors for fresh and processed samples. The results of convectively dried fresh samples confirmed that a long drying at high temperature causes a meaningful color change as a consequence of biochemical reactions (e.g. Millard polycondensation).

Table 2. Colorimetric data

Osmotic Agent	Cp (%)	ΔE (-)	ΔE00 (-)
Glucose	20	11.84±0.09	9.87±0.01
	40	6.76±0.14	4.03±0.01
	60	3.26±0.39	2.58±0.01
Fructose	20	10.19±0.2	5.76±0.01
	40	10.34±0.37	5.43±0.01
	60	11.27±0.35	4.09±0.01
Sucrose	20	12.84±1.65	9.90±0.01
	40	11.00±0.13	7.19±0.01
	60	12.95±0.24	8.30±0.01
CV		**17.01±0.13**	**11.52±0.01**

Cp – concentration; ΔE and ΔE00 – relative color change parameters

Application of OD pretreatment resulted in color better preservation. The influence of the solution concentration on the sample color was noticed only in the case of glucose solutions. The more concentrated solution was applied the smaller color change was obtained. For the two other osmotic agents (fructose and sucrose) the color change in dependence on solution concentrations was imperceptible and hardly to observe. The best color of samples after drying was gained for those dewatered in glucose solutions, while the worse one for the samples with sucrose solution pretreatment.

CONCLUSIONS

On the basis of presented results the following conclusion can be drawn:

1. The solution concentration has decisive influence on the effects of the OD process (WL, SG, ODR_{max}, MC_f). The higher solution concentration the bigger amount of water is removed from material (WL-increased, MC_f-decreased), however, more solute solid penetrated the cells of carrots (SG-increased).
2. The type of osmotic agent has an insignificant influence on OD effects such as WL, SG, MC_f (these parameters did not differentiate more than 0.5 $g/g_{(wb)}$), but has an influence on ODR_{max}. The highest ODR_{max} value was obtained for 60% solution of glucose (2.38×10^{-2} g/min) whereas the lowest one for 20% sucrose solution (4.33×10^{-3} g/min).
3. The OD process did not shorten CV drying to a meaningful degree. Although, for fructose and glucose the time of drying was shorter in comparison to drying of not pretreated samples, but for sucrose this time was similar or even longer. This phenomena can follow from the income of solute solid and crystallization of substances on the sample surface, which blocked the moisture outflow.
4. The OD process leads to changes on sample appearance. The sample shape and deformation change depend on the solution concentration. The smallest changes occurred for 20 % solution and the biggest for 60 %.
5. On the basis of the colorimetric analysis and the photos visualization it can be stated that the OD process influence positively the final product quality. Samples initially dewatered with osmotic solutions better preserved their color, structural and textural properties. The shape deformations and shrinkage were very similar in both osmotically pretreated and not pretreated samples.

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