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Chemical and Process Engineering 2015, 36 (3), 345-354

DOI: 10.1515/cpe-2015-0024

DRYING OF RED BEETROOT AFTER OSMOTIC PRETREATMENT: KINETICS AND QUALITY CONSIDERATIONS

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This article presents experimental studies on drying kinetics and quality effects of red beetroot (*Beta vulgaris* L.) after convective drying with a preliminary osmotic pretreatment. The effects of the osmotic agent (NaCl) concentration and the osmotic bath time on the product colour and nutrient content preservation, the water activity, and rehydration ability after drying were analysed. Osmotic dehydration curves and Solid Gain (SG), Water Loss (WL), Weight Reduction (WR) were determined. It was proved that drying of beetroot with osmotic pretreatment contributes to shorter drying time, smaller water activity, higher retention of betanin, better colour preservation, and a greater degree of water resorption.

Keywords: osmotic dehydration, drying kinetics, product quality, degree of rehydration

1. INTRODUCTION

Fresh fruits and vegetables contain more than 80% of water and therefore are highly perishable (Pabis and Jaros, 2002). Because of putrefaction processes, long storage of fresh vegetables and fruits is not possible (Mujumdar, 2007). Drying with osmotic dehydration (OD) as a pretreatment process is one of the ways to preserve long lasting durability of fruits and vegetables (Nastaj and Witkiewicz, 2004; Pabis, 1999).

The osmotic dehydration is a process of water removal from fruits and vegetables by their immersion in a hypertonic (osmotic) solution (Chua et al., 2004). During OD the mass transfer proceeds in two directions, water diffuses from the biomaterial to hypertonic solution and the solute diffuses from the solution to biomaterial. Usually, the rate of water loss (WL) is higher than the rate of solid gain (SG) in osmotically dehydrated biomaterial (Kowalska and Lenart, 2001). The driving force by water transport from the biomaterial tissue into the solution constitutes the osmotic pressure of the hypertonic solution (Sagar and Kumar, 2010). The dehydration process takes place up to establishing the equilibrium of chemical potentials between the osmo-active solution and the biomaterial cell. The rate of diffusion depends on factors such as: temperature and concentration of osmotic solution, size of material and its geometry, the ratio of solution-to-material mass, and the level of solution agitation (Rastogi et al., 2002).

Recent research shows that osmotic dehydration improves nutrient content, sensory and functional properties of food, texture and stability of pigments (Chavan and Amarowicz, 2012). The OD process reduces the moisture content and thus the time of product exposition to high temperature during further drying. As a consequence the OD process minimalises the danger of texture damage as well as colour and flavour change (Khan, 2012; Pakowski and Adamski, 2007; Piasecka et al., 2012; Witrowa-Rajchert and Rząca, 2009).

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Most dried products are rehydrated prior to their final use. The rehydration test of dried products is used to characterise the quality index indicating the physical and structural changes occurred during drying at given process conditions (Vadivambal and Jayas, 2007). Another important qualitative parameter is the water activity (a_w), which defines the microbial stability of the material. Lower water activity plays a role in higher food preservation (Mputu and Thonart, 2013). No microbial growth occurs when a_w is below 0.6 (Adams and Motarjemi, 1999).

The red beetroots is rich in valuable active compounds such as betanin, carotenoids, saponins etc. (Figiel, 2010). A red pigment of this vegetable is known as belatain, and 75-95% of it is made up of batanin. The average amount of this pigment is about 200 mg per 100 g of red beetroot; unfortunately, it degrades when subjected to light, heat and oxygen (Kowalski and Szadzińska, 2014). Red beetroot is widely used in industrial production as a natural red food colourant (Glokhale and Lele, 2011), and is used to improve the red colour of tomato pastes, soups, desserts, jams, sweets, ice cream, cereals, etc. (Glokhale and Lele, 2012). The color and flavour of dried food products are considered to be the most important quality attributes affecting the degree of acceptability of the product by the consumer (Sorour and El-Mesery, 2014). The colour of fresh vegetables depends on the composition and content of natural dyes. However, they are not very durable substances and their transformation during processing and storage causes discolouration (Kowalski and Szadzińska, 2014).

The applied method of drying may affect to a higher or lesser degree the colour change parameter value, water activity, rehydration, and nutrient content. Convective drying is usually considered to be an unfavorable method which negatively changes the parameters of the valuable ingredients (Vadivambal and Jayas, 2007). Therefore, this article proposes a way of improving the quality indicators of red beetroot through the application of osmotic dehydration, as a pretreatment before its convective drying.

2. MATERIALS AND METHODS

2.1. Material

Red beetroot *(Beta vulgaris* L.*)* was purchased on the local market. Fresh material of initial water content in the range of 0.87-0.89 kg/kg wb was purified, peeled and cut into circular discs 50 mm in diameter and 3 mm thickness. Each drying process was performed in duplicate.

2.2. Experimental Procedure

Osmotic dehydration was carried out in 5%, 15% and 25% solutions of NaCl (w\w) for 30, 60 and 90 min, respectively, then drained with a paper towel, and next samples were dried convectively in a hybrid dryer (Ertec, Poland) shown in Fig. 1.

During convective drying the cool air was supplied from the surroundings and heated in the electric heater to the temperature of 65°C and then fed by the fan to the drying chamber (internal dimensions of drying chamber 35x32x21 cm). Such a temperature is considered to be optimal for drying of fruits and vegetables (Jayaraman and Das Gupta, 2007). The velocity of air flow was 1.2 ± 0.1 m/s. The mass of drying sample was measured all the time using a balance (RadwagWPS2100C/1, Poland), and the temperature of material surface was recorded by a pyrometer installed in the drying chamber. All drying parameters were continuously recorded during drying processes with a standard personal computer equipped with data acquisition software. Each experiment was performed in duplicate.

Initial moisture content was determined using a moisture analyser (Precise Switzerland). The mass of dry sample was determined after 24-hour convective drying at 75°C in a SML42/250/M dryer produced

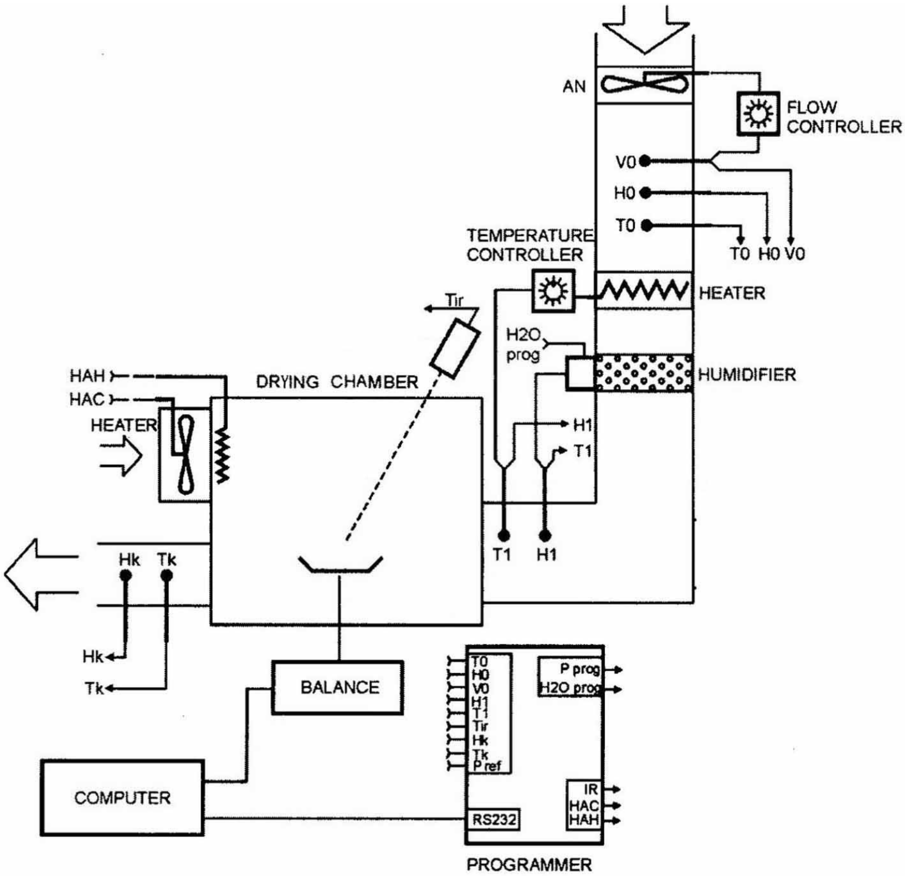

Fig. 1. Scheme of dryer (Kowalski and Rajewska, 2009)

by Zalmed (Poland). The current moisture content (MC) (kg/kg wet basis) was determined using the formula:

$$MC(t) = \frac{m_t(t) - m_d}{m_i} \tag{1}$$

where $m_t(t)$ [kg] denotes the sample mass measured at time t and m_d [kg] is the mass of the dry sample after osmotic dehydration, m_i [kg] is the initial mass of the sample.

2.3. Quality Assessment

The effectiveness of osmotic dehydration was determined by the following parameters: Solid Gain (SG), Weight Reduction (WR) and Water Loss (WL). SG value represents the amount of solid diffused from the hypertonic solution into the biomaterial, the parameter WR indicates the sample mass reduction due to OD process, and WL parameter determines the amount of water lost by biomaterial during the OD process. The parameters SG, WL, WR are defined as follows (Manivannan and Rajasimman, 2009):

$$WR = \frac{m_i - m_{OD}}{m_i} \tag{2}$$

$$SG = \frac{M_{OD} - M_0}{m_i} \tag{3}$$

$$WL = SG + WR \tag{4}$$

One of the most important qualitative parameters of a sample is the total colour change (ΔE) of the material after drying with respect to the fresh one. A value of ΔE was determined using the colourimeter CR-400, Konica Minolta (Japan), colour space with 0.01% precision. The colour of red beetrot samples was indicated by CIELab colour scale L^*, a^*, b^*, where L^* denotes lightness, a^* expresses the colour change from red to green, and b^* represents the colour change from yellow to blue The colour parameters were measured both after the osmotic dehydration and after the convective drying and referred to the colour of the fresh sample. Next, the resultant colour change ΔE was calculated using the formula (5):

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \tag{5}$$

where $\Delta L^* = L_p^* - L_s^*$, $\Delta a^* = a_p^* - a_s^*$, $\Delta b^* = b_p^* - b_s^*$ which correspond to colour changes between black and white, red and green, yellow and blue, and the subscripts p and s refer to the pattern and to the sample, respectively.

Each colour measurement was repeated 25 times. The arithmetic averages of colour parameters were assessed in the final calculations.

Water activity a_w determines the content of free water in the sample at which microorganisms can grow (Rahman and Labuza, 2007). The a_w parameter was measured with the accuracy of 0.001 using a humidity and temperature sensor equipped with the function of water activity measure system 650 / 0628.0024 Testo (Germany).

A method of betanin content measurement in the material was proposed by Nilson (1970). Betanin was extracted with phosphoric buffer (pH = 6.5) and then analysed spectrophotometrically (UV-2401PC of Shimadzu, Germany) for the absorbance of 538 and 600 nm. The betanin indications were repeated fifteen times.

Rehydration is a process used to assess structural changes of dried food products, and thus can be considered as a measure of the harm caused by drying (Sunil et al., 2013). The relative sample weight gain (P) measures a degree of water saturation of dry material during the rehydration process. The relative weight gain is calculated from the formula [Witrowa-Rajchert, 2004]:

$$P = \frac{m_{sr}(t)}{m_{ir}} \tag{6}$$

where $m_{sr}(t)$ is the mass of water during rehydration, m_{ir} is the mass of water in a fresh sample.

The value of parameter P was determined by immersing a dry sample in distilled water at the room temperature of 20°C. Measurements were performed by weighing the samples in the time intervals of 0, 30, 60, 90, 120, 150, 180, 210, 240, 270, and 300 min, enabling the determination of rehydration kinetics.

3. RESULTS AND DISCUSION

Figure 2 presents the drying curves of the samples with and without osmotic dehydration. The convective drying (CV) of not osmotically dehydrated (OD) samples was carried out to visualise the influence of OD pre-treatment on the drying time of beetroot. Theoretically, the samples with initial osmotic dewatering should dry faster because of smaller MC than in fresh material (Kowalski and Mierzwa 2011). Nonetheless, shorter drying time by CV drying of OD samples compared to not OD ones was observed only for those dewatered at 5% and 15% at concentration. For the samples with 25% concentration of NaCl, the time of CV drying was very similar or even longer in comparison to not OD samples. Differences between particular results follow from the transfer of solute solid and crystallisation of substances on the sample surface. The salt was settled on the sample surface and blocked up the moisture outflow. This is possibly the main reason for the insignificant shortening of the drying time and increasing the MC_f with respect to that in pure convective drying.

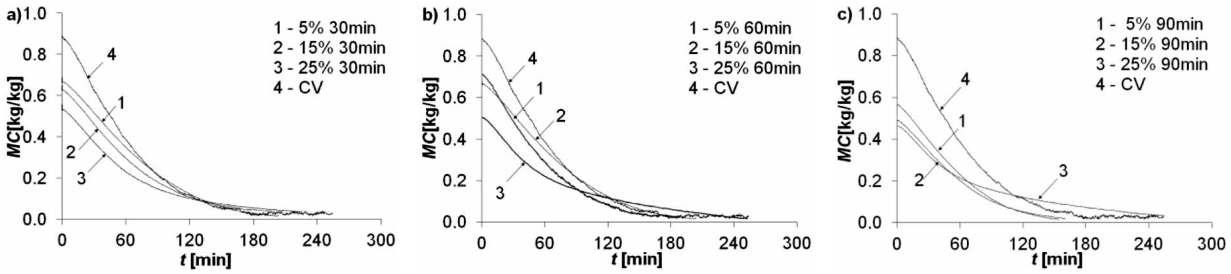

Fig. 2. Convective drying curves of fresh samples and those treated with osmotic dehydration for: a) 30 min b) 60 min c) 90 min

The curves in Fig. 3 present the reduction of moisture content *MC(t)* in time during the osmotic dehydration (OD) for 30, 60 and 90 min in a hypertonic solution of three different concentrations.

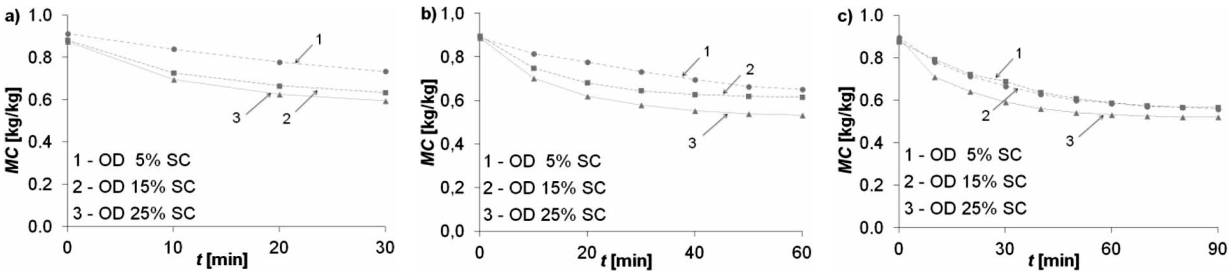

Fig. 3. Relationship of MC versus time for samples treated with osmotic dehydration for: a) 30min b) 60min c) 90 min

It can be seen that the moisture content decreases faster in the solutions with increased osmotic agent concentration (SC). It follows also from the dewatering curves that the *MC* decreases with the length of the OD time. The smallest final value of *MC* was obtained for the 25% SC and 90 min dewatering time. Besides, one can confirm the phenomenon known also from the literature (Jayaraman and Das Gupta, 2007) that NaCl used as the osmotic agent constitutes an effective driving force for osmotic dehydration. However, the dehydration efficiency here is not so significant as that in the case of the red beetroot samples dehydrated in a sucrose solution (Kowalski et al., 2013).

The characteristic parameters for OD defined by formulas (2) to (4) are collected in Table 1.

Table 1. The values of Weight Reduction, Solid Gain, Water Loss and water activity of samples dried by convection

	WR [kg/kg]	SG [kg/kg]	WL [kg/kg]	a_w [-]
OD 5% 30 min	0.18±0.01	0.01±0.01	0.18±0.01	0.427±0.01
OD 5% 60 min	0.26±0.01	0.04±0.01	0.3±0.01	0.419±0.013
OD 5% 90 min	0.28±0.02	0.1±0.02	0.38±0.02	0.388±0.02
OD 15% 30 min	0.24±0.02	0.01±0.02	0.24±0.02	0.414±0.011
OD 15% 60 min	0.28±0.02	0.06±0.02	0.34±0.02	0.401±0.015
OD 5% 90 min	0.28±0.02	0.1±0.02	0.38±0.02	0.388±0.014
OD 25% 30 min	0.34±0.02	0.01±0.02	0.35±0.02	0.407±0.011
OD 25% 60 min	0.31±0.02	0.05±0.02	0.36±0.02	0.372±0.01
OD 25% 90 min	0.37±0.02	0.14±0.02	0.51±0.02	0.347±0.013
CV	–	–	–	0.440±0.015

Another important indicator of product quality was the water activity (a_w), which affects many factors that determine product stability, e.g. development of microflora. Basically, a microbiologically safe biomaterial is characterised by the water activity of less than 0.6. However, this value does not exclude enzymatic browning. The enzymatic browning occurs unfortunately mostly in the water activity ranging from 0.5 to 0.8 (Adams and Motarjemi, 1999). The a_w value of fresh sample was equal to 0.96±0.02. A reduction of water activity due to drying, minimises the loss of food bioproducts resulting from microbial activity.

The results of measurements of a_w in dry material are shown in Table 1. As follows from these results, the water activity values after drying for all drying tests were below 0.5. Therefore, many harmful biochemical reactions responsible for material spoilage are slowed down. The value of water activity for drying process with OD pretreatment is lower than that determined for the drying test without OD. A decrease of a_w parameter with increasing both SC and time of OD was observed and the lowest values equalled 0.347±0.013 for 25% SC and 90 min OD. The lowest value of a_w was probably due to the longest convective final drying step necessary for the sample to be osmotically dehydrated at the highest salt concentration.

Another tested parameter referring to material quality was the total colour change. The measurements of colour changes for different drying tests are shown in Fig. 4.

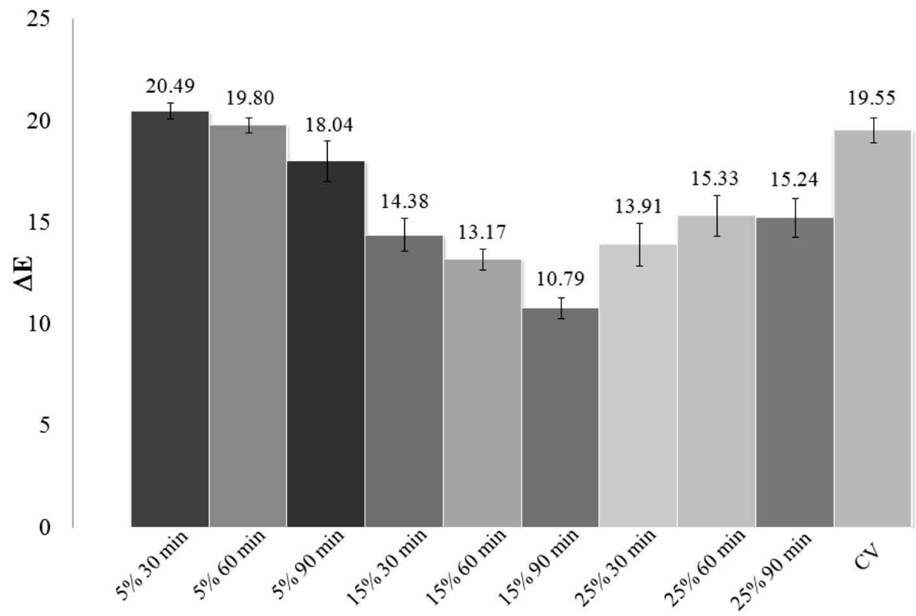

Fig. 4. Relative colour change after CV samples and those treated with osmotic dehydration

The height of the bars in the bar chart (Fig. 4) indicates that the lowest value of total colour change of 10.79±0.51 was obtained for CV drying with preliminary 90 min OD in 15% SC. The highest values of total colour change were reached for CV (19.55±0.81) and for CV with OD in 5% SC. The latter values amounted to 20.49±0.37, 19.80±0.37 and 18.04±0.91 for the osmotic dehydration time 30 min, 60 min and 90 min, respectively. In the case of OD in 25% SC the value of colour change was higher than that for OD in 15% SC. This can be explained by the fact that during OD the deposit of undissolved salt particles on the sample surface resulted in an increase of Δl^* parameter, which was responsible for the lightness of the material and thus also for an increase of the total colour change parameter ΔE.

Different trends were noticed in the investigation of the betanin retention. Fig. 5 shows that the highest content of this dye of 83.72±0.29% was gained for CV drying with preliminary OD in 5% SC. It was also observed that an increase of SC and OD time decreases the percentage of betanin retention. The lowest content of betanin equal to 30.76±0.41 was obtained for CV drying with 90 min OD in 25% SC. The values of betanin retention for CV drying with each OD in 5% SC were higher than those for pure CV drying, that is, higher than 59.35±1.11%. This reveals a positive effect of osmosis as far as it concerns the content of betanin retention (Kowalski and Szadzińska, 2014).

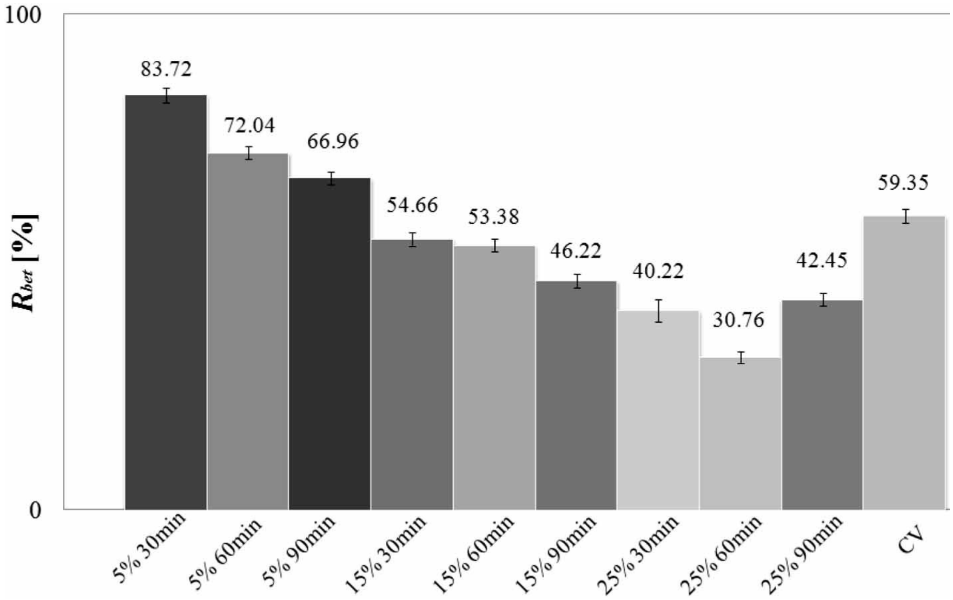

Fig. 5. Relative retention of betanin after CV samples and those treated with osmotic dehydration

The values of the relative mass gain *P* by rehydration in demineralised water for 5 hours are presented on the bar chart in Fig. 6. The bars in this figure illustrate the ability of samples being dried in different conditions to be resaturated with water. The height of a bar indicates the biomaterial structure damage. A greater height of a bar denotes less damaged structure of biomaterial. It can be noticed from Fig. 6 that by a shorter OD time (30 min) the biomaterial structure was less damaged in each case. The highest value of saturation equal to 0.84 was obtained for CV drying with 30 min OD in 15% SC. The lowest value of this factor was reached for CV drying with 90 min OD in SC 25%. This fact can be explained by the transfer of solute solids and crystallisation of these substances on the sample surface during the OD process. The salt settled on the sample surface blocked the moisture outflow during convective drying, thus increasing the moisture pressure which is favourable to sample structure damage. Similar results showing the decreasing rehydration ability after OD because of clogging pores by the osmotic agent were obtained by Kowalski and Szadzińska (2014).

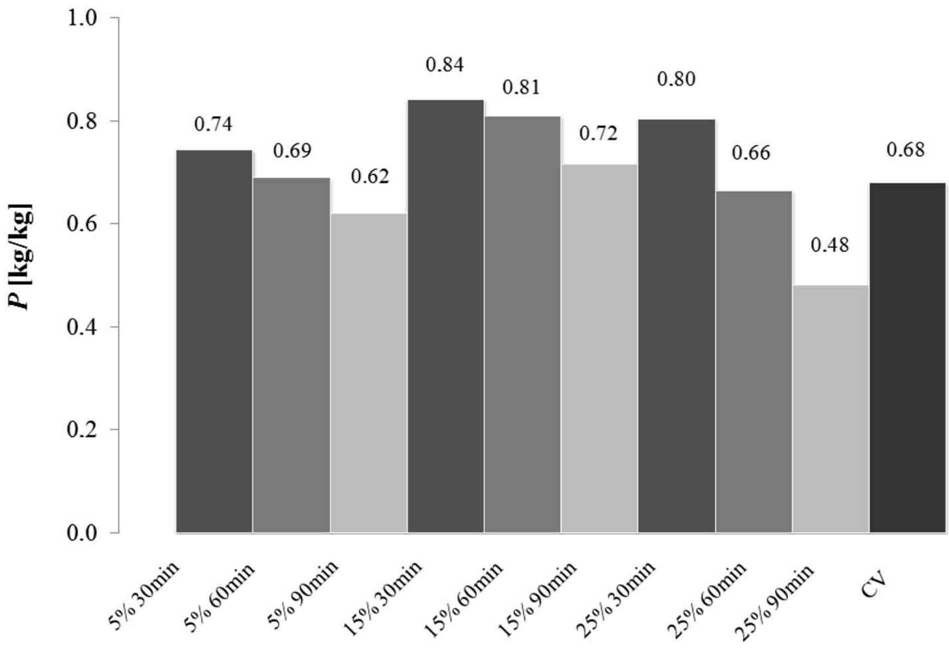

Fig. 6. Relative water mass gain in rehydration process after CV samples and those treated with osmotic dehydration

4. CONCLUSIONS

The present study revealed better effectiveness of convective drying (CV) of red beetroot preceded with osmotic dehydration (OD). The osmotic pretreatment of this product prior to convective drying enhances drying kinetics and improves quality factors such as colour change, water activity, retention of betanin, and rehydration ability.

It is concluded that OD of beetroots in hypertonic solutions of 5% and 15% NaCl solid concentration (SC) before CV drying shortens the drying time up to 35% in comparison to pure CV. The value of sample water activity a_w after CV drying with OD is significantly lower than that after drying without OD, particularly with increased SC and OD time. The lowest value of a_w amounting to 0.347±0.013 was attained for 25% SC and 90 min OD. The highest value of betanin retention amounting to 83.72±0.29% was reached for CV drying with 30 min OD in 5% SC. The parameter of total colour change was the lowest (10.79±0.51) for CV with 90 min OD in 15% SC. The highest total colour change was recorded for pure CV drying. The best dry sample rehydration of 0.84 was obtained by rehydration after CV drying with preliminary 30 min OD in 15% SC.

One can state that the osmotic pretreatment of beetroot samples before CV drying improves the product quality and partly also the drying kinetics. NaCl hypertonic solutions can be considered as good osmotic agents for red beetroot pretreatment. It gives a positive impact on product quality and for small values of SC also on drying kinetics.

This work was carried out as a part of the research project 03/32/DS-BP/0505 sponsored by Poznań University of Technology

SYMBOLS

a^*	colour parameter from red to green, -
a_w	water activity, -
b^*	colour parameter from yellow to blue, -
L^*	lightness, -
m	mass, kg
M	dry mass after OD, kg
MC	moisture content (wet basis), kg/kg
P	relative water gain, kg/kg
R_{bet}	betanin retention, %
T	temperature, °C
SC	solution concentration, %
SG	Solid Gain, kg/kg
WL	Water Loss, kg/kg
WR	Weight Reduction, kg/kg
ΔE	relative colour change parameter, -

Subsscripts

d	dry
i	initial
ir	initial mass of water in the fresh sample
OD	after OD
sr	water in the sample during rehydration
t	time
0	without OD

Abbreviations

CV	convective drying
OD	osmotic dehydration

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Received 24 March 2015
Received in revised form 24 July 2015
Accepted 25 July 2015