

EFFECTS OF PRETREATMENTS OF SLICED VEGETABLES WITH TREHALOSE ON DRYING CHARACTERISTICS AND QUALITY OF DRIED PRODUCTS

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Abstract: Effects of pretreatments with trehalose on drying of sliced vegetables (potato and carrot) were experimentally investigated. Two different pretreatment methods were tested. Sliced vegetables were steam-blanching and then immersed in a sugar solution. In another method sliced vegetables were coated with sugar powder, and then steam-blanching. Solid gain and water loss during pretreatment were measured. The isothermal drying experiments were carried out at 303, 313 and 323 K. Sorption isotherms of dried samples were determined by a standard gravimetric method at 303, 313 and 323 K. Pretreatments reduced the water content of vegetable samples due to osmotic dehydration. Less shrinkage, better colour properties and better cell reconstruction properties were observed for samples pretreated with trehalose either with solution or with powder.

Keywords: vegetable drying; trehalose pretreatment; osmotic dehydration, sorption isotherms.

INTRODUCTION

In addition to liquid foods and semi-solid foods, agricultural products such as vegetables and fruits are currently being dried and distributed to food processing companies. The purpose of such food drying processes is not only to reduce the volume and weight of the products but also to improve the product stability (shelf life) whereas the product quality must be maintained during and after drying.

Research and developments of new preservation methods are continuously carried out in order to improve the quality of the final product. For drying of vegetables and fruits, freeze-drying (FD) is known to be a good method, by which product shrinkage is eliminated or minimized, and a near-perfect preservation results are expected (Moreira *et al.*, 1998). FD also prevents heat damage and produces products with excellent structural retention (Lin *et al.*, 1998). However, as FD is a costly process, it is only suitable for high-value products (Lin *et al.*, 1998).

More economical methods that can produce high quality dried products are required. Although conventional hot air drying is a cheaper method, it has several disadvantages

such as non-uniformity of the dried sample, slower drying rates and lower quality of the resulting products. These, however, can be improved using a combination of different drying methods. Beaudry *et al.* (2004) compared combined osmotic dehydration of cranberries with microwave-assisted convective drying, convectional hot air-drying, freeze-drying and vacuum drying. Osmotic dehydration is a viable process for partial removal of water in materials with cellular structure (such as fruits and vegetables). In recent years, osmotic dehydration has received considerable attention due to low operating temperature and reduced energy requirements (Robbers *et al.*, 1997). In most osmotic dehydration, sucrose is used.

Pre-drying treatments such as addition of sugars are needed for vegetable drying in order to avoid damages to tissue structures. Previous work has shown that non-reducing disaccharides such as sucrose and trehalose can protect biological systems from the adverse effects of freezing and drying (European Patent Application, 1999). Especially trehalose is known to have many advantages. For example, sweetness of a 10% trehalose solution is 45% as that of a 10% sucrose solution. Trehalose is a non-reducing sugar and therefore does not react with amino acids or proteins to

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cause Maillard browning. Consequently, deterioration caused by Maillard reaction such as loss of nutrition can be avoided in addition to protection of flavour and colour (<http://www.cargill.com/sfi/treappl.htm>).

Pretreatment with trehalose solution has been claimed to be very effective for producing high quality dried vegetable-chips (Saito, 2001). Aktas *et al.* (2004) found that pretreatment with trehalose solution improved the reconstitutive properties of dried sliced carrot and potato samples compared with the dried products pre-treated with sucrose solution, which is generally used for osmotic dehydration (Figure 1). Osmotic treatment is a simultaneous water and solute diffusion process (Rastogi *et al.*, 2004). Many studies showed that sucrose treatment increases the water loss compared with the other osmotic solutions (Reppa *et al.*, 1998; Antonio and Murr, 2002; Khiabani *et al.*, 2002).

However, to our knowledge effects of pre-treatments with trehalose on drying/dehydration behaviour, sorption isotherms of dried vegetables and dried product qualities were not investigated fully.

In this study effects of pretreatment of sliced vegetables with sugars on drying/dehydration behaviour, and sorption properties and quality of dried vegetables were investigated experimentally. As model vegetables potato and carrot were chosen. Trehalose and sucrose were employed as a pretreatment reagent. Isothermal drying experiments were carried out with samples prepared with different pretreatments. Static sorption experiments were performed to determine sorption isotherms of dried vegetables with different pretreatments.

MATERIAL AND METHODS

Sample Preparation

Carrot and potato were selected as sample vegetables because they are popular in the foodstuff industry and daily products that are extensively consumed due to nutritional value and sensory properties. Before drying the sample vegetables were cleaned, peeled and sliced manually by using a vegetable slicer. For most experiments the sample thickness is 1 mm. The sliced samples were cut into a round shape (20 mm diameter) by means of a round shape cookie cutter. In this way disk-shaped samples having the same area and the thickness were prepared. Then, the samples were blanched with steam for 3 min for carrot, 4 min for potato (Swanson, 2003). The purpose of blanching is to inactivate enzymes responsible for deterioration of fresh vegetables such as peroxidase and polyphenoloxidases. Samples should not be cooked by steam blanching. We measured the peroxidase activity using hydrogen peroxide and guaiacol. As for sugar-pretreatments, two methods were employed. The first method uses a 20% sugar solution, in which blanched samples were soaked for a specified time. In the second method, sliced samples were coated with sugar powders, and then steam-blanched.

Determination of Water Loss And Solid Gain During Pretreatments

Blanched samples were dipped in a sugar solution of a specified concentration for an assigned time. Water loss and solid gain were calculated from the following equations

(Antonio and Murr, 2002):

$$WL = \frac{(W_{w0} - W_w)}{M_0} \times 100 \quad (1)$$

$$SG = \frac{(W_s - W_{s0})}{M_0} \times 100 \quad (2)$$

where, WL and SG are water loss and solid gain in %, respectively. W_s is the solid mass at time t , W_{s0} is the initial solid mass, W_w is the mass of water at time t , W_{w0} is the initial water mass, and M_0 is the initial mass (water + solid) of the fresh sample (prior to blanching).

Drying Experiments

Isothermal drying experiments were performed in a constant-air temperature box (Adhikari *et al.*, 2002; Yamamoto *et al.*, 2002; Yamamoto, 2004). Temperature was kept constant within $\pm 0.5^\circ\text{C}$. This drying equipment consisted of two fans, which circulated the air keeping it well mixed, a fan control unit, a heater, a temperature control unit and a digital balance. The drying air velocity was ca. 1.5 m s^{-1} (measured by a hot wire digital anemometer). The relative humidity in the constant-air temperature box was maintained by using a desiccant (silica gel). Sufficient amount of silica gel was kept within the box to keep the air dry throughout the experiment. The air relative humidity in the drying box was maintained below 1% during experiments, which was checked by using a hygrometer (VAISALA HM70, VAISALA Japan, Tokyo).

The sample was placed onto a wire net cage, which was attached to an aluminium dish. The aluminium dish eliminated unwanted vibrations of the wire net cage by the hot air stream. The dish was pendant from an electronic balance placed on the drying chamber. The sample weight measuring interval was 5 min at the initial period, and then it was increased to 30 min with the progress of the drying.

The solid mass of samples W_s was determined with a direct heating method using Mettler PM400 model infrared dryer at 105°C until the weight stayed constant (2–4 h).

Sorption Isotherms

To obtain sorption isotherms (equilibrium water content X versus water activity A_w), dried samples were stored in an airtight plastic container in the presence of saturated salt solutions of known A_w values (Troller and Christian, 1978; Rahman, 1995). Then the samples were weighed periodically until the weight loss became less than 2% per 12 h (Yamamoto *et al.*, 2002). Experiments were carried out at 303, 313 and 323 K.

The sorption isotherms determined were fitted by the GAB equation (Weisser, 1984; Van Den Berg, 1984; Rahman, 1995), which is known to be a standard isotherm equation for foods.

$$X = \frac{X_m C K A_w}{(1 - K A_w)(1 - K A_w + C K A_w)} \quad (3)$$

Here X is (equilibrium) water content and X_m is water content when each sorption site contains one molecule (monolayer). C and K are constants, which are related to the energies of

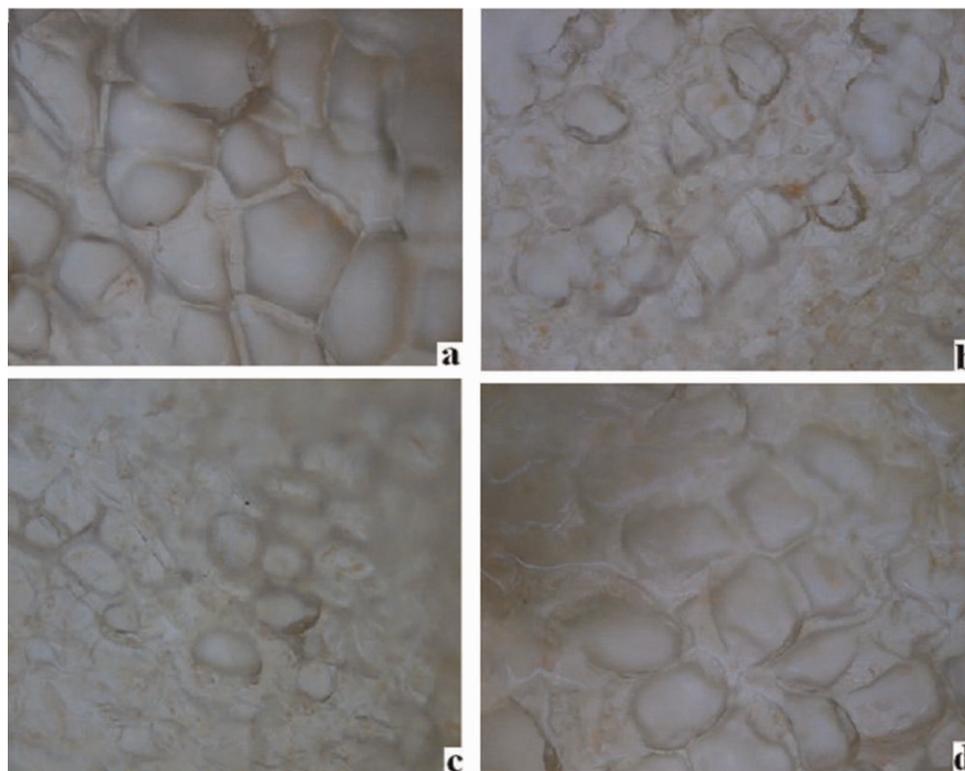


Figure 1. Microscopic pictures of cell structure of carrot samples after osmotic pre-treatments: (a) non-treated, (b) blanched, (c) dipped into sucrose solution, (d) dipped into trehalose solution) (Aktas *et al.*, 2004). This figure is available in colour online via www.icheme.org/fbp

interaction between the first and further sorbed molecules at the individual sorption sites.

RESULTS

Mass Transfer During Pretreatments

Solid gain (SG) and water loss (WL) of carrot samples after pretreatments with different process time and sugar concentration are shown in Figure 2. Both increasing process time and sugar concentration increased with SG and WL values. Generally SG and WL values treated with sucrose were higher than those treated with trehalose. Potato samples

showed larger SG and WL values compared with those of carrot samples at the same conditions. For example while WL value for the samples pretreated with sucrose that have 40% concentration and 30 min was determined as 15.8% for carrot samples, this value was determined as 52.7% for the potato samples. SG values for the carrot and potato samples treated in same way were determined as 14.5% and 41.8%. These values were determined rather lower when trehalose pretreatments applied. Large WL values indicate strong effect of osmotic dehydration. However, at the same time considerable amounts of sugars are uptaken by sliced vegetables, which is not preferred. So, in the

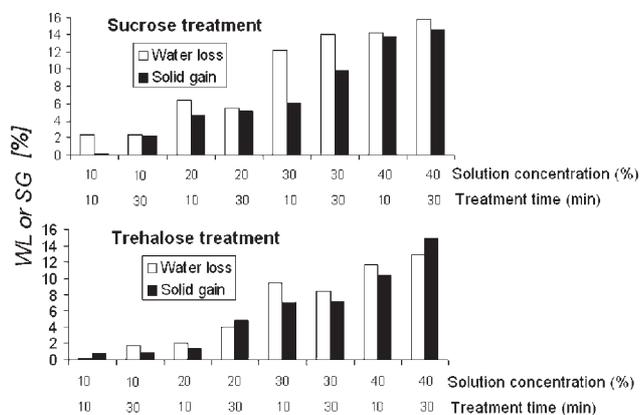


Figure 2. Water loss and solid gain of carrot samples during pretreatment with sugar solutions.

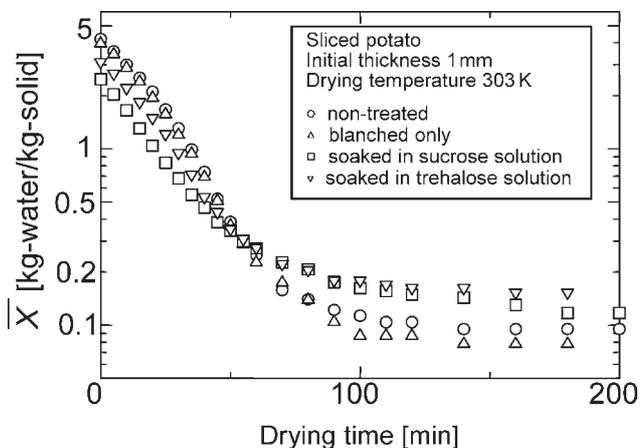


Figure 3. Drying curves of sliced potato sample with or without pretreatments.

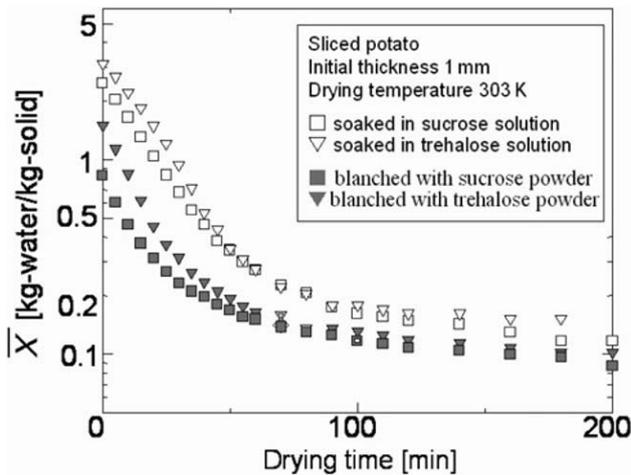


Figure 4. Drying curves of sliced potato sample with different pretreatments.

following experiments we chose a process (soaking) time of 10 min in a sugar solution of 20% concentration.

Effects of Pretreatments on Isothermal Drying

Isothermal drying experimental data for potato samples prepared with different pre-treatments are shown in Figures 3 and 4. As seen in the Figure 3, initial water content values X_0 lowered due to osmotic dehydration effects by sugar pretreatments compared with non-treated samples. The maximum decrease in the X_0 of samples occurred when soaked in sucrose solution (Figure 3). The osmotic dehydration effects were more significant with the powder treatment (Figure 4). Although non-treated samples showed higher drying rates at the end of the drying compared with samples soaked in sucrose and trehalose solutions, this may be due to irregular and very significant shrinkage of the non-treated samples. Due to such irregular shrinkage

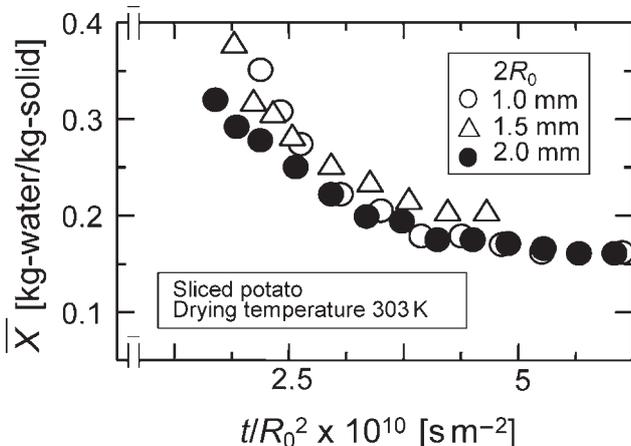


Figure 5. Drying curves of sliced potato samples with different thickness values. Samples were pretreated with trehalose solution after blanching.

the drying curve of non-treated samples is not reproducible compared with sugar-pretreated samples. On the other hand, trehalose solution treated samples showed reproducible drying data. And consequently, as shown in Figure 5, the data with different thickness samples were expressed similarly based on the normalized time, t/R_0^2 , which is derived from a diffusion model (Crank, 1975). As seen in Figure 5, drying curves of the potato samples that have different thickness are similar at the end of the drying process.

As for the two different pretreatment methods, the treatment with blanching using sugar powder showed lower initial water content and higher drying rate at the end of the drying process (Figure 4). The reason for the higher drying rate is not clear as the final dried product showed similar appearance.

Effects of Pretreatments on Sorption Isotherms

Sorption isotherms for dried carrot and potato samples with different pretreatments are shown in Figure 6. The sorption

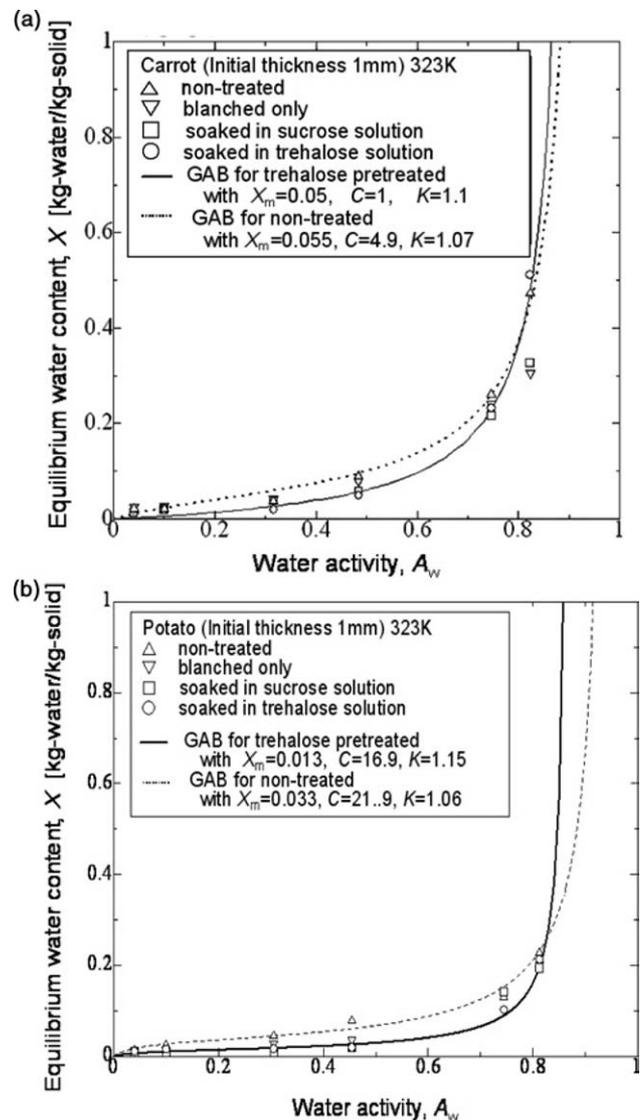


Figure 6. Sorption isotherms of dried vegetable samples: (a) carrot samples; (b) potato samples.

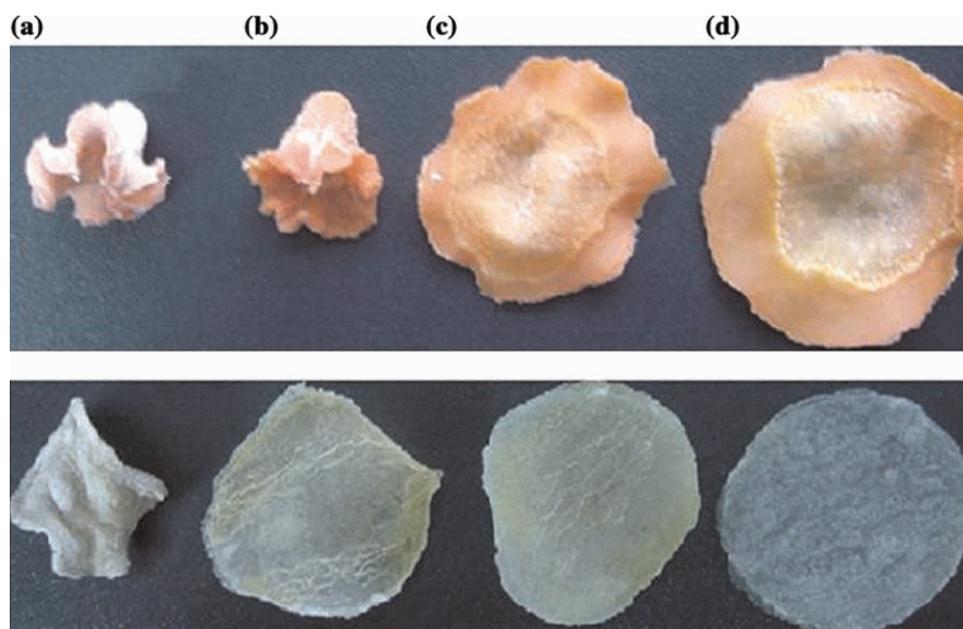


Figure 7. Photographs of sliced carrot (upper) and potato (lower) samples after drying at 323 K: (a) non-treated sample, (b) blanched sample; (c) sucrose solution treated sample, (d) trehalose solution treated sample. This figure is available in colour online via www.icheme.org/fbp

isotherm data were fitted by the GAB equation, and the GAB parameters determined are shown in Figure 6(a) and (b) for carrot and potato samples, respectively. As seen in this figure, sugar pretreatments lowered the equilibrium water content for the water activity below 0.80. Especially trehalose pretreatment decreased the equilibrium water content for both carrot and potato samples.

The equilibrium water content at a given water activity (A_w) for the carrot samples treated with sugar solutions were lower than those for the blanched and untreated samples especially when $A_w < 0.75$.

Effect of Pre-treatments on Final Dried Product Appearance Properties

As mentioned previously and reported in the previous paper (Aktas *et al.*, 2004), pretreatments with a sucrose or trehalose solution provides dried sliced vegetables of good appearance compared with untreated samples (Figure 7). Changes in sample shape occurred mostly at the beginning of drying process. As seen in Figure 7, shrinkage was highly eliminated for both carrot and potato samples. While blanching process has good effect on the colour, it could not prevent the shrinkage of carrot sample. On the other hand sugar pretreatments especially trehalose treatments prevent the shrinkage distinctly either for carrot or potato samples in addition to preventing of colour.

It was observed that sucrose solution pretreatments made final samples softer. But using sucrose results in caramelization of the sample and made the sample sweeter. On the other hand, trehalose is less sweat whereas trehalose pretreatments allow the natural colour and flavour of the vegetables. In addition the replacement of reducing sugars with trehalose can help extend the shelf life of vegetables or foods that contain dried vegetables where browning contributes to colour change and flavour loss.

DISCUSSION

As pointed out by Nindo *et al.* (2003), drying of vegetables with hot air usually results in considerable shrinkage and formation of dense structure. Consequently, the reconstitution becomes slower. It is also known that the drying rate becomes very low at low water content regions. Several researchers investigated the effects of pretreatments on the drying rate and the product quality of vegetables (Dandamrongrak *et al.*, 2003; Latapi and Barrett, 2006; Nindo *et al.*, 2003). In these investigations either physical or chemical pretreatments with salts were tested. Studies on pretreatments of vegetables with trehalose for hot air drying are rarely found in the literature.

On the other hand, many studies have been carried out on protective effects of trehalose and other sugars on drying of proteins (or enzymes) and cells mainly based on aqueous glasses or vitrification (Crowe *et al.*, 1998, 2001; Franks, 1985, 1993, 2003). These investigations have shown that proteins are highly protected by amorphous aqueous sugar glasses. It is not clear whether these theories can be directly applied to vegetable cells. It is considered that cell membrane damage is responsible for death or inactivation of cells. However, it is quite complicated as some protectants can permeate the cell membrane while others can not. However, as pointed out by Crowe *et al.* (2001), trehalose may be a first choice as a protectant.

Higher drying rate at the initial stage may cause case hardening of the product surface (Nindo *et al.*, 2003), which results in significant, irregular shrinkage of the product. Due to osmotic dehydration by sugar pretreatments the water content before drying was already reduced. The drying rate was slowed due to the sugar pretreatments. These may be part of the reason of almost unidirectional homogenous shrinkage.

Reliable engineering data of the drying rate or the apparent water diffusion coefficients during drying of sliced vegetables are not available as they are dependent on the

drying conditions as well as the sample preparations or pretreatments. Our data have shown that the drying data can be described by the diffusion equation considering the water content dependent diffusivity (Yamamoto, 2001, 2004) whereas a rather complicated drying behavior was observed by the drying method similar to ours (Luyben *et al.*, 1980)

CONCLUSIONS

Two different pretreatment methods (solution or powder) with trehalose resulted in dried sliced potato or carrot disks without significant irregular shrinkage compared with samples without pretreatments,

During the pretreatment process, the water content of the sample decreased significantly due to osmotic dehydration.

Sorption isotherms of trehalose pretrated dried vegetables showed lower equilibrium water contents compared with non-treated samples.

NOMENCLATURE

A_w	water activity
C	GAB sorption constant related to monolayer properties
K	GAB sorption constant related to multilayer properties
M_0	initial mass (water + solid) of the fresh sample (prior to blanching), kg
R_0	initial half thickness of sample, mm
SG	solid gain, %
t	time, s
WL	water loss, %
W_S	solid mass at time t during soaking, kg
W_{S0}	initial solid mass during soaking, kg
W_s	solid weight in the absence of water, kg
W_w	mass of water at time t , kg
W_{w0}	initial water mass, kg
X	moisture content, kg-water/kg-solid
X_m	water content corresponding to monolayer coverage, kg-water/kg-solid
X_t	water content at time t , kg-water/kg-solid
X_0	initial water content, kg-water/kg-solid

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