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Osmotic Dehydration of Fruits and Vegetable

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Abstract

Osmotic treatment as a preparation step to further processing of plant and animal material allows to improve the overall quality of food products by modifying the composition and the structure of the material (substrate). In the study presented focus is given to the impact of the solution applied for the treatment on the composition of the processed substrates (dewatering, uptake of osmotic agent) and on the structural parameters (overall and cellular shrinkage, porosity); the process was carried out at moderate temperatures (25 – 45°C) and as substrate apples, carrots and potatoes were used. The impact of the concentration was studied using sucrose (0.5 – 5.3 m), that of the osmotic active components was analysed using binary (sucrose, glucose, sorbitol, glycerol, salt) and ternary (sucrose-salt) aqueous solutions with similar water activity (aw = 0.91 ± 0.01). Moisture diffusion coefficients were estimated from dewatering rates. It was observed that the dewatering effect is enhanced by increasing the solute concentration, the solute uptake however is limited because of a parallel increase of the viscosity of the solution which has to be considered as a restricting factor for the mass transfer by the substrate. An increase of the molecular weight of the osmotic active component of the solution enhanced the dewatering effectivity. The degree of permeability of the cell membranes for small molecules and ions affected considerably the dewatering effect and the solute gain. Furthermore the beneficial effects of an osmotic treatment as a pre-treatment to convective warm air drying was confirmed for dried carrot slices.

Keywords: osmotic treatment, sucrose, glucose, sorbitol, glycerol, salt, air drying

Introduction

Dewatering of plant and animal tissue by osmotic active substances is an old process, examples are candying of fruits and salting of fish or cheese. In the last twenty years in a period of exciting food engineering research activities the process received special interest with regard to its principles, potentials and industrial applications.

For osmotic treatment, food tissues are immersed in aqueous solutions of sufficiently high concentration at moderate temperatures. A water drain from the tissue into the solution takes place and a solute transfer from the solution into the tissue and a leaching process of the tissue's own solutes are observed. Although much of the initial water content can in this way be removed from the tissue, storage stability of the final product must be assured by another processing technique, as the water content of the osmotically treated product is still high enough to induce spoilage. Osmotic treatments have been studied in combination with air-, vacuum-, freeze- and sun-drying, pasteurising, canning, freezing, frying, addition of preservatives and/or acidification and coating by edible surface layers.

The current increase of interest in osmotic treatments arises primarily from the need for quality improvement and from economic factors. Quality improvement is related not only to the water removal with minimal thermal stress but also to the impregnated solutes and the modification of the structure (Torreggiani & Bertolo, 2001). With the correct choice of

solutes, and a controlled and equilibrated ratio of water removal and impregnation, it is possible to enhance natural flavour and colour retention in fruit products, hence to avoid additives such as antioxidants; softer textures in partially dehydrated products can be obtained; food ingredients can be designed for particular uses. The economic interest in osmotic treatments focuses on reduced energy consumption for water removal without phase change, as compared to convection drying, and the possible reduction of the refrigeration load by partial concentration prior to freezing of fruit or vegetables (Spieß & Behsnilian, 1998).

The effectivity of the treatment is generally evaluated in terms of the magnitude and the rate of water removal and the ratio of water removal to solute gain. The effectivity of osmotic treatment is affected by both the properties of the substrate and the processing conditions.

Concerning the substrate, Torreggiani (1995) observed that under the same processing conditions the dewatering effect is always higher for vegetables than for fruit. Furthermore the degree of ripeness of the fruit plays an important role with regard to the selection of the treatment parameters and the outcome of the process, mainly due to differences in the chemical (e.g. pectin and cellulose contents) and in the microstructural (e.g. porosity) characteristics of the material. A pre-treatment of the material such as blanching or freezing before the osmotic processing step destroys the integrity of cell membranes and favours the solute uptake (Torreggiani et al., 1990). Among the processing conditions that have an impact on the dewatering and solute impregnation achieved are: time, temperature, surrounding pressure, kind of contact between solid material and solution, weight ratio solid to solution, geometry of the solid material and composition of the solution.

The thermodynamic pre-requisite for water removal from plant material using osmotic treatment is that the water activity of the solution should be lower than that of the treated material. From the wide range of possible osmotic active solutes for the treatment, mono- di- and polysaccharides as well as common salt are the most frequently used, mainly due to the impact of the gained solutes on the sensory characteristics of end-products.

The composition of the solution plays a decisive role with regard to the modifications of the substrate. It is generally accepted that the rate of water removal increases with increasing concentration of the solution. The molecule size of the osmotic active solute may have an affect on the ratio water loss to solute gain. Lazarides (1994) showed that the an increase of the dextrose equivalent of starch syrups used for osmotic treatment enhanced the solute gain.

Intact cell membranes are no ideal semi permeable membranes, they show different degrees of permeability for small molecules and ions. The degree of permeability of membranes depends on the nature of the solute and on the structure of the membrane. The reflection coefficient (σ) is a measure of the relative permeability of a particular membrane to a particular solute. Furthermore water passes cell membranes by two routes: by diffusion through the lipid bilayer and through water channels called aquaporins. In plants the activity of these water channels can be decreased (thus decreasing the water permeability of the membrane) by different kinds of stress situations, such as the exposure to high osmotic pressure. Ye et al. (2004) demonstrated that inhibition of aquaporin activity increased with both increasing concentration and size of solutes. Summarily, the concentration of the solutes use in the treatment solution and their nature are of major importance for the dewatering effect and the solute uptake achieved by the osmotic treatment.

In the last years the use of multicomponent solutions has gained more and more interest. For example the use of ternary sucrose-common salt aqueous solutions is very widespread for the treatment of meat and fish (Collignan et al., 2001). The interest in the application of these ternary solutions relies in the accelerating effect observed in both the water removal and the solute gain (Collignan & Raoult-Wack, 1992).

This paper focuses on the effect that the composition of the solution has on the chemical and physical characteristics of the treated material. The impact on dewatering, cellular shrinking,

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uptake of osmotic agent and overall weight changes were studied for different plant tissues in sucrose solutions of varying strength at moderate temperatures. The effect of the osmotic active solute was studied using binary aqueous solutions of glucose, sucrose, glycerol and sorbitol and ternary aqueous solutions of sucrose-common salt, all with similar osmotic strength. The effect of processing parameters on the macroscopic and cellular shrinkage and on the evolution of tissue porosity and density were evaluated. The mass transfer data were used for calculating diffusion coefficients. Furthermore osmotic treatment as a pre-treatment for warm air drying was evaluated at the example of carrot slices.

Materials and Methods

Apple (Pirus Malus, var. Granny Smith), carrot (Daucus carota L., var. Puma and Nutri Red) and potato (Solanum tuberosum L., var. Nicola) were osmotically treated. Sucrose (refined, 99.9% sucrose), glucose (Merck, Germany), sorbitol (Merck, Germany), glycerol (Merck, Germany) and common salt (99.9% sodium chloride) were used as osmotic active solutes for binary and ternary aqueous solutions with concentration varying from 0.5 to 5.3 m.. Osmotic treatment was carried out up to 20 hours at temperatures between 25 and 45°C. For all experiments the ratio sample to solution was 1:20 (kg/kg).

The characteristic parameters for osmotic treatment were determined: water loss (W), solute gain (S) and weight loss (G) according to equations (1)-(3) and expressed in kg/kg.

$$W = \frac{(M_{Wt} - M_{W0})}{M_0} \quad (1)$$

$$S = \frac{S_t - S_0}{M_0} \quad (2)$$

$$G = \frac{(M_t - M_0)}{M_0} \quad (3)$$

M: sample weight in kg; M_W: kg water in M kg sample; S: kg sucrose, glycerol, glucose, sorbitol and /or NaCl in M kg sample; 0: initial conditions; t: sampling time.

The volume and bulk density of the samples was determined using Hubbard pycnometers with toluene (20°C) and the sample shrinkage (V/V_0) calculated according to equation (4):

$$\frac{V}{V_0} = \left(\frac{M_0 - M_t}{M_0}\right) \cdot \frac{\rho_0}{\rho_t} \quad (4)$$

V_0, V: volumes of the sample before and after osmotic treatment; ρ_0, ρ_t: density of the samples before and after osmotic treatment.

For cylindrical samples the length (h_0, h) and diameter (D_0, D) were determined with a sliding calliper before and after treatment and the data obtained were used to calculate the diameter shrinkage(s_D) and the length shrinkage (s_h) defined as:

$$s_D = \frac{D}{D_0} \qquad s_h = \frac{h}{h_0} \quad (5)$$

The overall volume of the tissue before osmotic treatment (V_0) can be expressed as the sum of the symplasmatic volume (V_{S0}: protoplasts), and of the apoplasmatic volume. The apoplasmatic volume is occupied by the cell walls (V_{CW0}) and included gas (V_{G0}). After osmotic treatment the tissue volume (V) can de expressed as the sum of volumes occupied by

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the symplasma (V_S), the cell walls (V_{CW}), the included gas (V_G) and the osmotic solution (V_L).

The volumes occupied by the included gas in the tissue before and after the treatment (V_{G0} and V_G) were calculated using equation (6).

$$V_G = \left(\sum_i m_i\right)\frac{\rho_S - \rho}{\rho_S \cdot \rho} \qquad \text{with} \qquad \rho_S = \frac{\sum_1 m_i}{\sum_i V_i} = \frac{\sum_i m_i}{\sum_i \frac{m_i}{\rho_i}} \tag{6}$$

ρ: density of the sample; m_i: mass of the different components (water, sucrose, polysaccharides, protein, fat) and their corresponding density ρ_i.

Considering water is removed from the symplasma V_S (m^3/kg) can be calculated according to equation (7):

$$V_S = V_{S_0} - \frac{(W + W_L)}{\rho_W} \tag{7}$$

W_L: water associated to the solutes gains (kg/kg); ρ_W: density of water at the treatment temperature (kg/m^3).

The volume occupied by the solution after the treatment was calculated with equation (8):

$$V_L = \frac{S \times V \times \rho_t}{c \times \rho_{OL}} \tag{8}$$

ρ_{OL}: density of the osmotic solution; c: concentration of the solution(kg/kg).

The porosity of the samples was calculated with equation (9):

$$\varepsilon = \frac{\rho_S - \rho}{\rho_S} \tag{9}$$

Total solids were determined gravimetrically by drying of the samples in a vacuum oven at 70°C until a constant weight was obtained. The sucrose content was determined by an enzymatic UV method (Boehringer Mannheim GmbH, Germany). The chloride content was determined using a chloride ion-selective electrode (Mettler-Toledo, Switzerland) with a Ion-Meter pMx 3000 (WTW, Germany).

The diffusion coefficients for moisture transport were estimated based on data derived from the dewatering observations and the solution of Fick's second law.

Osmotic treatment was applied to carrot slices (3 mm) as a preparation step to air drying. Osmotic treatment was performed at 25°C during 60 min using 3 aqueous solutions, all with a_W = 0.91: 0.15kg/kg sodium chloride, 0.62kg/kg sucrose and a combined 0.07kg/kg sodium chloride-0.34kg/kg sucrose solution. For the control samples with no osmotic treatment, a blanching process at 95°C, 1 min was applied. Convection drying was performed in pilot scale dryer (Heindl, Germany) at 70°C (Regier at al, 2005). Dried slices were stored up to 4 months under nitrogen atmosphere in photo resist bags at 25°C. Controlled quality parameters were: Vitamin C (Bognar & Daood, 2000) and carotenoid retention (Mayer-Miebach & Spiess, 2003).

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Results

Changes in the composition

With regard to a dewatering process in osmotic treatment sucrose solutions, immersion times not exceeding four hours are recommended. After this time the rate of the dewatering process decreases considerably independent of the treated tissue or the concentration of the solution (fig. 1a). Although the system is far away from the equilibrium, the rate of water removal decreases dramatically. The reduction of the water permeability of the membrane caused by the inhibition of the aquaporin activity, could be a possible explanation for this observation.

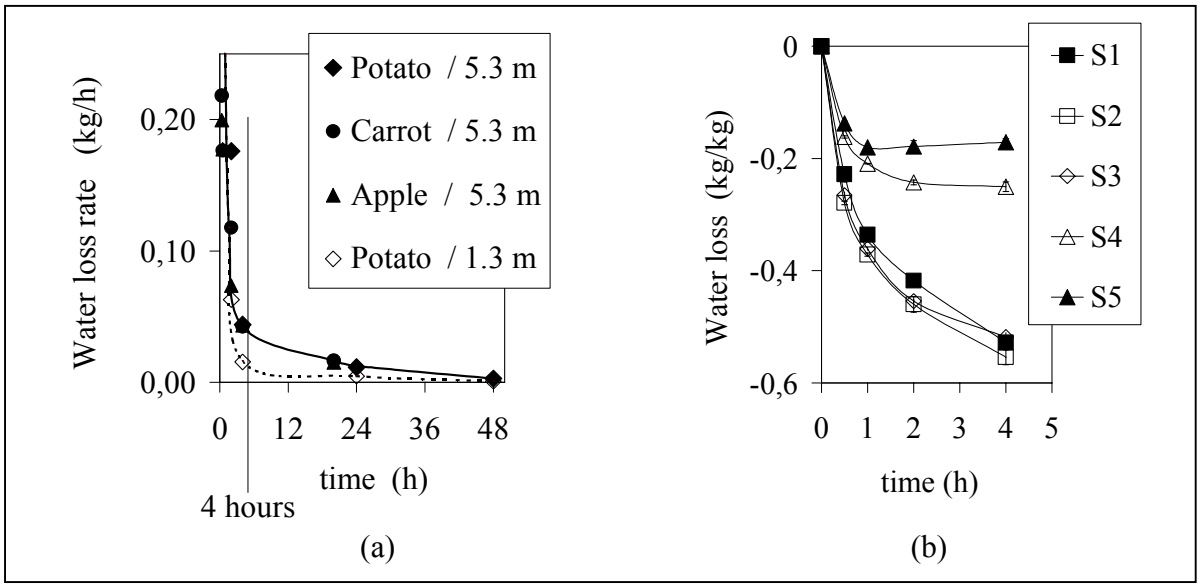

Figure 1: (a) Water loss rate (kg/h) for the osmotic treatment of potato, carrot and apple in 1.3 and 5.3 m sucrose solutions (25°C); (b) kinetic of the water loss (kg/kg) for the treatment of carrots in binary sucrose (S5) and NaCl (S1) and ternary sucrose-NaCl (S2, S3, S4) aqueous solutions (25°C). The composition of solutions S1-S5, all with aw = 0.91, is given in table 3.

For the treatment in solutions with high salt content much shorter treatment times are recommended when aiming at a dewatering effect. After a two hour treatment in a ternary sucrose-salt aqueous solutions with high salt content no more water is removed from carrot tissue (fig. 1b). Furthermore in the case of the treatment of carrots in a binary salt aqueous solution a maximal water removal is observed after one hour; after this time the carrots start to regain water. It can be assumed that at this point the cellular liquid begins to be replaced by the osmotic solution. Barat (1998) observed this behaviour after an exposure of many days when apples were treated in sucrose solutions.

For osmotic treatments in sucrose solution the temperature showed mainly an indirect effect on the overall water loss and solute gain within the studied moderate temperature range (25 – 45°C). An increase of the temperature results in a decrease of the viscosity of the sugar solution. This improves the surface contact between material and solution and results in an enhanced dewatering effect (tab. 1). In the case of apples an increase of the treatment temperature also favours the release of the gas included in the tissue, in the case of the apples

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under study the gas volume was up to 23% of the tissue volume. The gas release decreased the internal resistance to the mass transport and in this way enhanced the dewatering effect. An increase of the treatment temperature enhanced the weight loss of the material as a result of the enhanced water loss. No effect of temperature was observed on the solute gain for osmotic solutions having a concentration m> 2 (tab. 1). At lower concentrations of the solution an increase of the temperature was related with an increase of the solute gain.

Table 1: Water loss, solute gain after 4 hours osmotic treatment in 5,4 m sucrose solution at different temperatures. Moisture diffusion coefficients (D_W, $10^{10}m^2/s$), maximal diffusion coefficient (D_0; 10^7 m^2/s) and activation energy (Ea, $kJmol^{-1}K^{-1}$) for the treatments.

Material	25°C			35°C			45°C			D_0	E_a
	W	S	D_W	W	S	D_W	W	S	D_W		
Apple	0.32	0.07	2.6	0.39	0.07	3.2	0.47	0.07	3.8	2	16.0
Carrot	0.43	0.05	3	0.52	0.05	4.5	0.56	0.05	5.1	7	18.7

The dewatering effectivity, defined as the ratio water loss to solid gain, of binary aqueous solutions of different sugars and polyols (a_w = 0.91) increased with increasing molecular weight of the osmotic active component of the solution: glycerol < glucose ≈ sorbitol < sucrose (fig. 2).

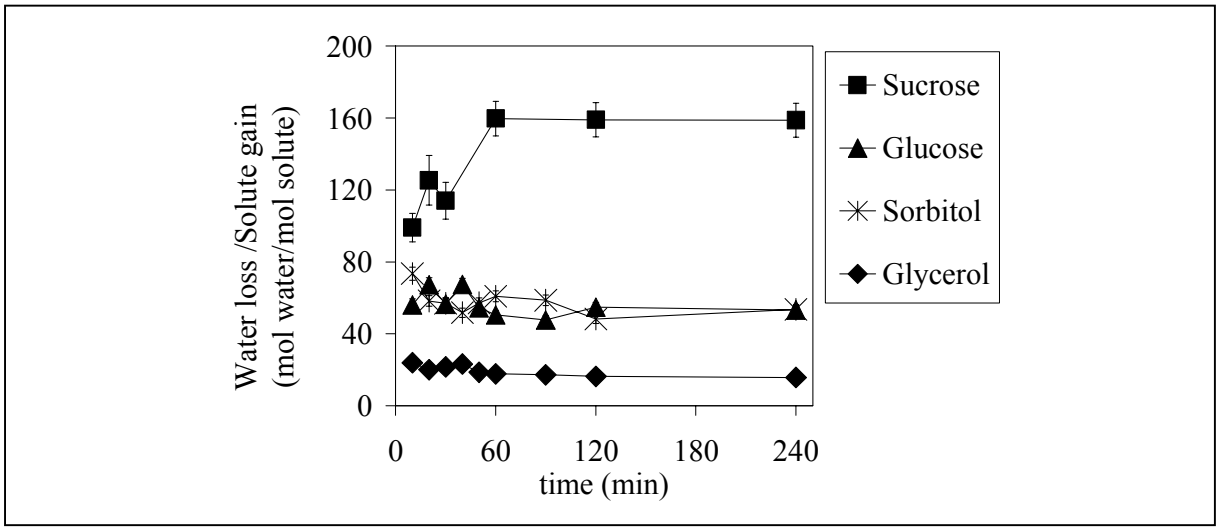

Figure 2: Effect of the osmotic active solute on the dewatering effectivity of the solution (a_w = 0.91) for the osmotic treatment of carrots. Dewatering effectivity: Water loss / Solute gain (mol_{water}/mol_{solute}).

The highest water loss was achieved with glucose solution (tab. 2), the sample is however very intensively impregnated with glucose, therefore glucose solutions are considered not as effective as sucrose solutions with regard to the dewatering effect. In case the solute gain is expressed in kg/kg only small differences are observed between glycerol and glucose or

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sorbitol. However when using different solutes, the number of moles gained instead of the gained weight should be compared (tab. 2). Considering this type of comparison it can be stated that the glycerol uptake is most pronounced. Plant aquaporins facilitate the transcellular movement of water, but, in some cases, also a flux of small neutral solutes such as glycerol across a cellular membrane is observed (Chaumont et al., 2005). This could explain the high glycerol uptake observed.

Table 2: Water loss (W) and solute gain (S) for carrots after 4 hours osmotic treatment in solutions with a_W = 0.91; X_L= Water content of the solution; D_W moisture diffusion coefficients.

Osmotic active solute	Molecular weight g/mol	X_L kg/kg_{dm}	W kg/kg	S kg/kg	S mole/kg	D_W 10^{10} m^2/s
Glycerol	92.08	0.59	0.37	0.12	1.3	2.4
Glucose	180.16	1.00	0.57	0.11	0.6	6.8
Sorbitol	182.17	1.08	0.51	0.10	0.5	3.4
Sucrose	342.30	1.56	0.51	0.06	0.2	2.7

Osmotic active solutes with a low reflection coefficient such as glycerol (σ = 0.8) or NaCl (σ = 0.5 – 0.6), are able to penetrate the cell membrane. Osmotic solutions of this kind of solutes are adequate when the main goal of the treatment is to achieve a high impregnation of the tissue related with a low dewatering. After 20 hours osmotic treatment in a 5.4 Osm sucrose solution the water removal from potatoes averages 0.60 kg/kg, but only 0.16 kg/kg in a 5.4 Osm NaCl solution. At the same time sucrose uptake seems to be more pronounced by the potato tissue, 0.13 kg/kg as compared to 0.09 kg/kg in the case of NaCl, but using mole/kg as the unit to express the solute gain it evident that more NaCl (1.54 mole/kg) is taken up than sucrose (0.38 mole/kg).

In sucrose-NaCl ternary aqueous solutions the sucrose gain is enhanced with increasing NaCl (tab. 3). With increasing NaCl in the solution the carrot tissue gains more moles sucrose from the available sucrose in the solution (m_{OL}). Sucrose seems to have the opposite effect towards NaCl, it acts limiting the NaCl uptake. The addition of a very low amount of sucrose reduces the approximately 30% the NaCl uptake (compare solutions S4 and S5 in Table 3).

Table 3: Concentration of sucrose and NaCl (kg/kg) in the binary and ternary aqueous solutions (aw=0.91±0.01); corresponding solute gain for carrots after 4 hours treatment expressed in kg/kg and as m_c/m_{OL} with m_c=moles sucrose or NaCl gain per kg carrot and m_{OL}= molality of sucrose or NaCl in the solution.

Osmotic solution			Sucrose gain		NaCl gain	
Nr.	Sucrose	NaCl	kg/kg	m_C/m_{OL}	kg/kg	m_C/m_{OL}
S1	0.615	-	0.064	0.04	-	-
S2	0.510	0.027	0.075	0.07	0.001	0.02
S3	0.339	0.069	0.071	0.12	0.050	0.42
S4	0.005	0.138	0.013	0.21	0.073	0.42
S5	-	0.149	-	-	0.107	0.61

Process parameters and changes in the structure

During osmotic treatment not only the composition of the tissue is changed but also the structure. Depending on achieved degree of water removal, protoplasts shrink, plasmolyse and are even destroyed. Furthermore the porosity of the material is affected and an overall shrinkage of the tissue is observed. All these changes influence the mass transport during the treatment and the quality of the treated material.
The bulk density of the treated material increases as a result of the substitution of parts of the water present in the material with osmotic solution, and the liberation of part of the gas included in the tissue. This is the case for potatoes and carrots (fig. 3a). However, apples contain a great volume of included gas, of which only a small portion is liberated during the treatment. This explains why, after treatment in high concentrated sucrose solutions (m> 3.5), products with lower bulk density than the fresh material can be obtained.
The porosity of the treated material is always higher as of the fresh material. Even potatoes and carrots which have a very low porosity (0.01 and 0.02 respectively) in the fresh state show this behaviour. For short time treatment in 5.4 m sucrose the porosity of apple samples increased from aprox. 0,20 up tp 0.30 at 45°C (fig. 3b). The gas release out of the tissue can be recognised already after 60 minutes at 25°C and 30 minutes at 35°C.

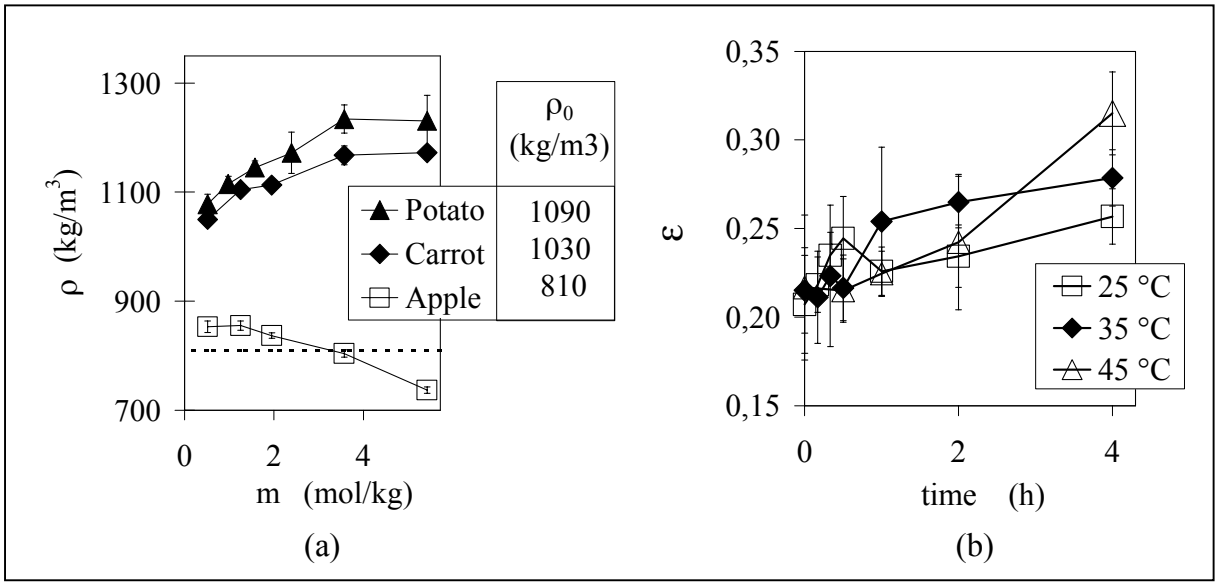

Figure 3: (a) Bulk density (ρ) of potato, carrot and apple after 20 hours osmotic treatment in sucrose solution as a function of the concentration of the solution, ρ_0= bulk density before the treatment (T = 25°C); (b) Kinetic of the changes in the porosity of apples for different temperatures in 5.4 m sucrose solution.

Plant tissue shrinks during the osmotic treatment as a result of the water removal from the symplasma (protoplasts). The course of the overall shrinkage depends strongly on the structure of the treated material. When the mass transport during osmotic treatment is considered a simplified isotropic shrinkage model is generally assumed. However this simplified consideration does not reflect the real situation as it has been shown at the example of apples and carrots (Fig 4).

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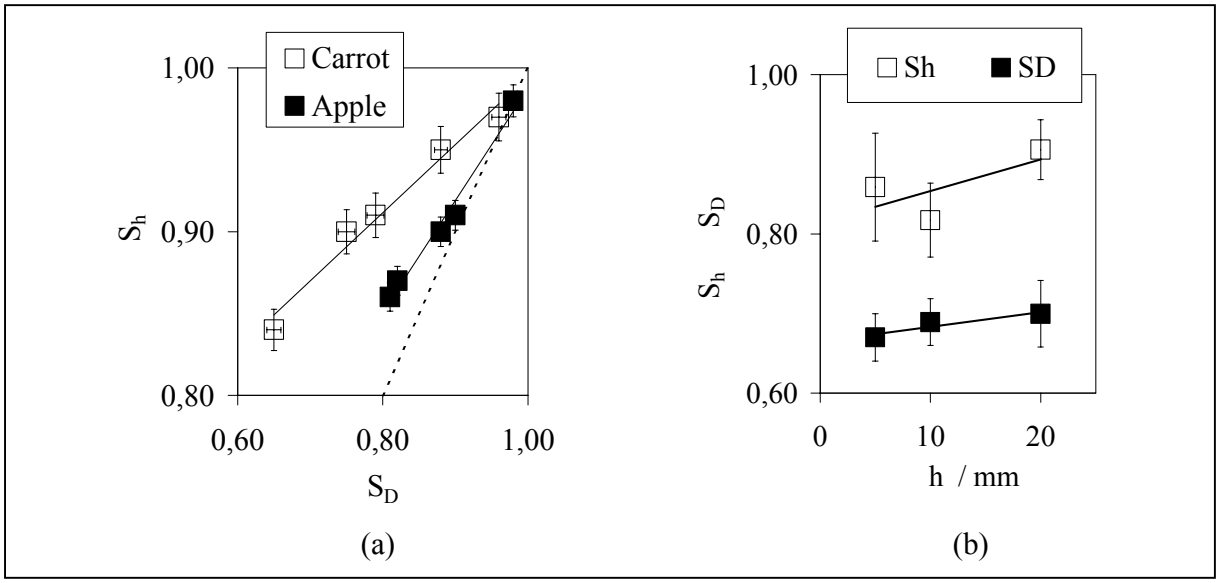

Figure 4: (a) Anisotropic shrinkage of apples and carrots; (b) shrinkage of the length (S_h) and of the diameter (S_D) of cylindrical carrot samples for different cylinder lengths (h) (5.4 m sucrose solution, T = 25°C, t = 20 hours).

With increasing concentration of the solution the size of the material decreased for all three tissues as consequence of the water removal. The macroscopic overall shrinkage (V/V_0) is lower than the shrinkage of the symplasma (V_S/V_{S0}) (fig. 5). The reason for this is the generation of a intracellular space (V_L), as a result of the retraction of the cell membrane from the cell wall, which is occupied by the osmotic solution in course of the osmotic treatment.

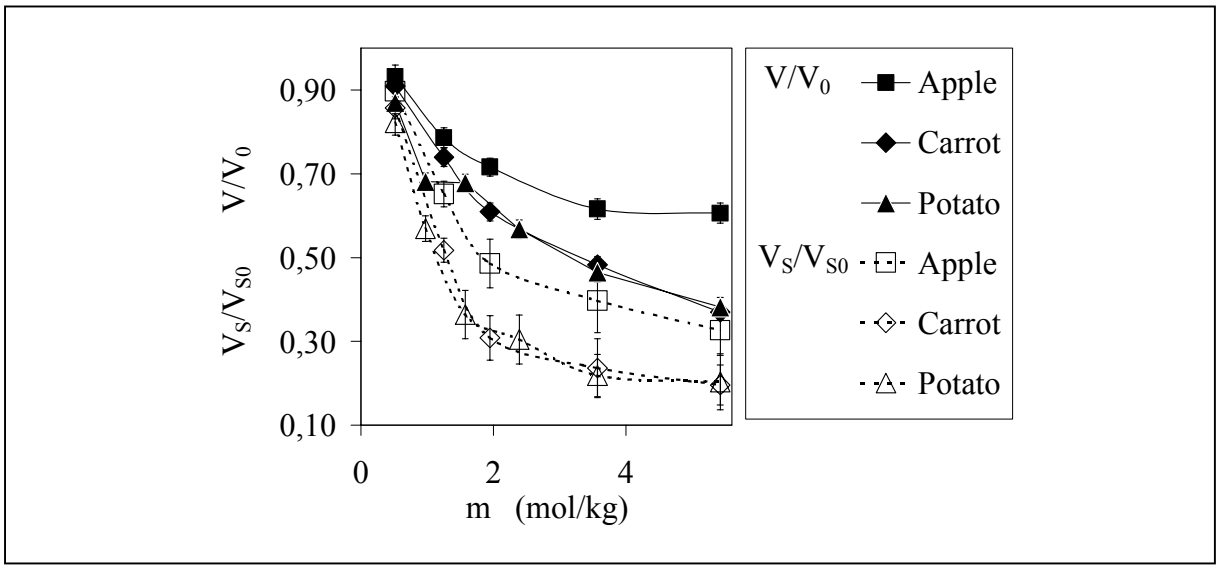

Figure 5: Overall macroscopic shrinkage (V/V_0) and symplasma shrinkage (V_S/V_{S0}) for apple, carrot and potato samples after 20 hours osmotic treatment in sucrose solutions as a function of the molality of the solutions (T=25°C).

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The calculated symplasma volume changes represents the changes of the total volume occupied by the protoplasts, not the changes of single protoplasts. In the course of the treatment protoplasts shrink, to some degree they are also destroyed. For this reason the symplasma shrinkage is expected to be higher than the shrinkage of single protoplasts obtained by direct microscopic observations. For osmotic treatment in 4.6 m sucrose solution Ferrando and Spiess (2003) determined by direct microscopy a maximal protoplast shrinkage of 0.4 for onion protoplasts and of 0.6 for strawberry protoplasts, but at the same time the cell viability was reduced up to 25%. The calculated symplasma shrinkage when treating with 4.6 m sucrose was 0.35 for apple tissue and 0.20 for carrot and potato.

For long time treatments the symplasma shrinks markedly with increasing concentration of sucrose solutions until a critical volume is achieved (fig 5, 6). For all tissues studied this critical volume of the symplasma was observed when using a 1.95 m sucrose solution for the osmotic treatment. When this critical volume of the symplasma is achieved, the tissue collapses and the cell walls shrink together with the protoplasts. In relative diluted sucrose solutions, the shrinkage of the symplasma is larger than that of the entire tissue and volume occupied by the solution increases with increasing concentration. For these solutions the protoplasts plasmolyse, but are basically not destructed; furthermore the cell walls are little affected by the treatment, as shown by Nieto et al., 2004; by observation of the microstructure of apple tissue. In concentrated sucrose solutions the shrinkage of the symplasma is proportional to the shrinkage of the entire tissue, $V_S/V \approx 0.5$ (fig. 6). With increasing sucrose concentration, not only the protoplasts are affected but also the cell walls (Chiralt et al., 2005) and the tissue shrinks entirely, together with protoplasts and cell walls.

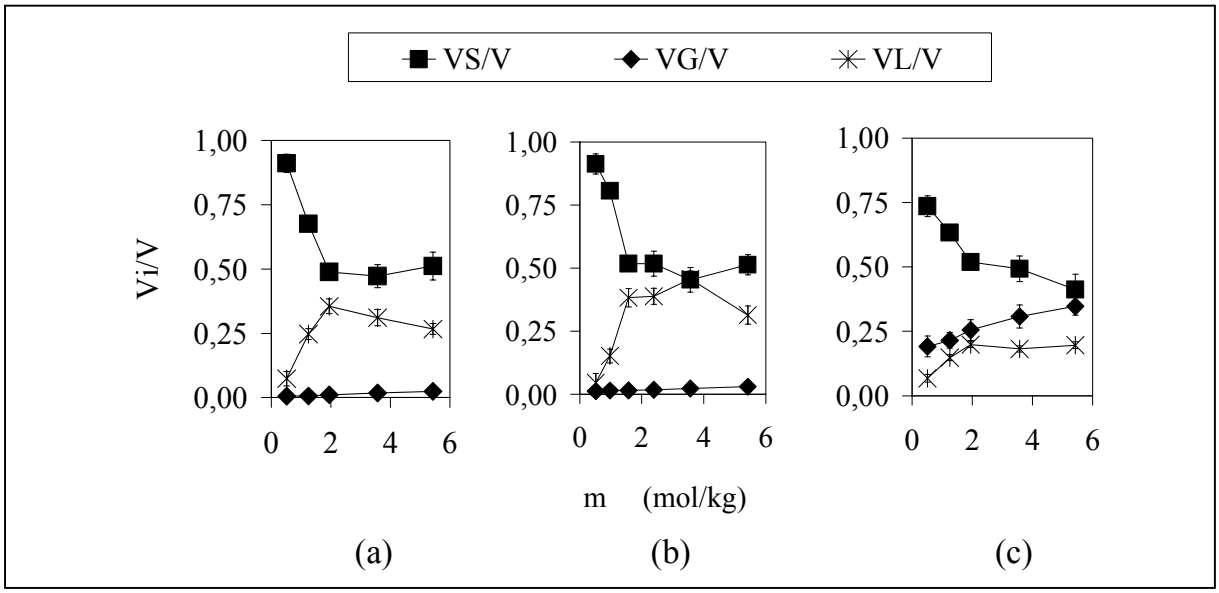

Figure 6: Symplasma (V_S), volume occupied by the solution (V_L) and volume occupied by the included gas (V_G) related to the total volume (V) for (a) carrot, (b) potato and (c) apple tissue after 20 hours osmotic treatment in sucrose solutions as a function of the molality of the solutions (T=25°C).

Remarkable is the large volume occupied by the included gas in apple tissue, which made up to 35% of the total volume after 20 hours in 5.4 m sucrose solution. This explains also the apparent low V_S/V achieved with this sucrose solution. If the volume of the symplasma is

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related to the volume of the tissue excluding V_G, $V_S/(V-V_G)$, a lowest value of 0.63 is obtained for this solution.

Warm air drying

A main part of the water present in the fresh carrots is removed during the osmotic treatment at 25°C, e.g. after 60 min osmotic pre-treatment in a sodium-chloride-sucrose solution the water content (X) is reduced from 8.9 kg/kg $_{d.m.}$ to 1.7 kg/kg $_{d.m.}$.
After osmotic pre-treatment the thermal stress for achieving products with X=0.015 is radically reduced: using a ternary sucrose-sodium chloride aqueous solution air drying times can be reduced up to 50% as compared to the drying of material not pre-treated (fig.7).
As both, sucrose and sodium chloride, have been proposed as retarding or inhibiting the oxidation of ascorbic acid by different mechanisms (Hsieh & Harris, 1993; Harel, 1994), an enhanced retention of this phytochemical can be expected when applying an osmotic pre-treatment in sucrose or sodium chloride solution. During osmotic treatment a slight leaching of the Vitamin C was observed. However, after convection drying, osmotic pre-treated carrots showed a much higher Vitamin C retention compared to blanched carrots. According to McLaughlin & Magee Vitamin C degrades exponentially during drying. The shorter drying times of pre-treated carrots could partly explain the better retention. However a protective effect from sucrose is also confirmed: carrots pre-treated in sucrose or in sodium chloride solutions need the same drying times to reach the desired product, however almost 80% of the initial vitamin C is retained when treating in sucrose and only 50% when treating in sodium chloride. Furthermore pre-treating in a ternary solution leads to an excellent retention, even after 2 months storage.

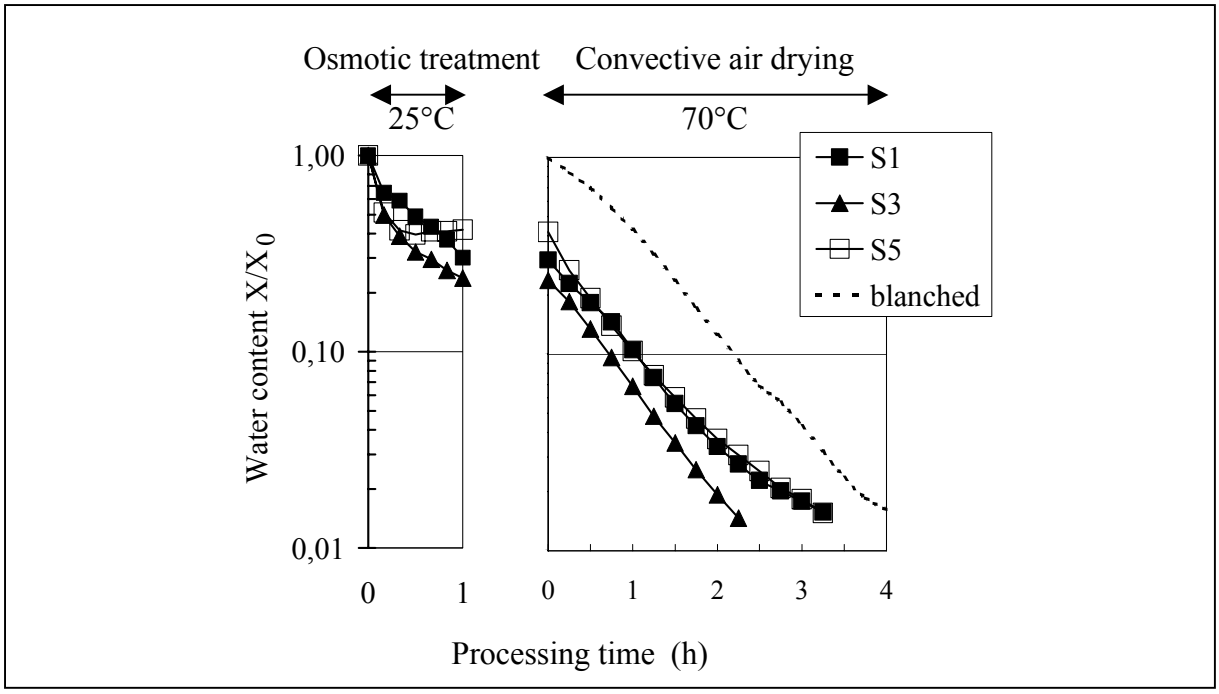

Figure 7: Kinetic of the water removal from carrot slices during osmotic pre-treatment in three different solutions (S1, S3, S5) and further convection drying and blanched carrot slices during convective drying. The composition of solutions is given in table 3.

Concerning carotenoid retention, the osmotic pre-treatment had no significant effect. Only with the pre-treatment in sucrose solution, a slight enhancement of the carotenoid retention has been observed.

Conclusions

It has been shown that the composition of the solution plays a decisive role is in terms of the modifications achieved in the treated material. Here are both the kind of solute and their concentration determinants.
An increase of the concentration of sucrose solutions is associated with an enhancement of the dewatering effect but not with an increased uptake of sucrose, being the viscosity of the solution a limiting factor for this issue. An increase of the molecular weight of the osmotic active component of the solution enhanced the dewatering effectivity.
Not only the osmotic effect of the solute is important for the effectivity of the osmotic treatment but also the permeability degree of cell membranes for small molecules and ions.
The use of ternary sucrose-salt aqueous solutions showed to be very effective concerning the water removal from vegetables. The composition of the osmotic solution must be optimised regarding the further process applied. Important for the choice of the adequate solution is the effect of the gained solutes upon the further processing step and the stability of significant nutritional components, as well as upon the sensory characteristics of the product.
Plant tissue shrinks during the osmotic treatment as a result of the water removal from the symplasma. To describe the shrinkage behaviour the microstructure of the plant tissue should be considered, since simplified isotropic shrinkage models do not reflect the real situation during osmotic treatment.
The beneficial effects of an osmotic treatment on dried carrot slices has been proved. The drying time of carrot slices was reduced and the retention of physiological active compounds enhanced. Reduced processing times at higher temperatures could also reduce processing costs. A financial study of the complete process including recycling of the osmotic solution is needed to confirm this point.

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