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OSMOTIC PRESSURE INFLUENCE ON THE VEGETABLE CHIPS DEHYDRATION PROCESS

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Abstract: The low fruit and vegetable consumption identified by the World Health Organization is a significant factor for adverse health consequences, like obesity and noncommunicable diseases. In the worldwide effort of boosting fruit and vegetable consumption to at least five servings of fruits and vegetables per day (5-A-Day), healthy, mildly sweet and salty dried crunchy vegetable snacks can add up increasing attractiveness of vegetables among youngsters.
The objectives of this research were to obtain sweet and salty dried parsnip snacks, pretreated with concentrated whey (CW) and concentrated hydrolyzed whey (HW), to study the influence of osmotic pressure and temperature (45, 55 and 65 °C) on the convective drying process and to estimate the kinetic parameters (diffusion coefficients, activation energy) of parsnip drying.
Nonlinear regression models were applied to estimate the drying parameters based on Henderson - Pabis equations. Results have shown that the activation energy required during drying by the chips treated with HW (23.89 $kJ\cdot mol^{-1}$) and CW (20.06 $kJ\cdot mol^{-1}$) is lower than in the reference sample (31.02 $kJ\cdot mol^{-1}$).
Moreover, these represents a smart valorization of a by product from dairy industry rich in valuable minerals, proteins and sugars in the veggie industry.

Keywords: *drying, parsnip, vegetable snacks, whey*

INTRODUCTION

The recommended consumption of at least five servings of fruits and vegetables a day (5-A-DAY) indicated by World Health Organization [1] combined with the increased consumer demand for minimally processed (MP), fresh-like foods is streaming food industry towards developing new convenient category of foods, minimal processed, able to promote a healthy and nutritious life style.

In the food industry drying is mostly performed for food preservation in order to extend its shelf life. This method of preservation ensures a low-quality decay rate over storage that result from a reduced water activity in dehydrated products, which retards microbial and enzymatic activity.

Often blanching is the treatment that precedes drying and it can be applied either at high temperature and short time (HTST) or at low temperature and long time (LTLT). LTLT has the advantage of, minimizing the quality loss of nutrients in the final product (vitamins denaturation, enzymes inactivation, minerals) and the changes in product appearance, flavor and/or texture [2]. However, blanching mainly increase the water content of the system that has to be later removed by drying, thus, in order to make drying process cost effective the pretreatment applied to fresh fruit and vegetables should not add if not reduce the water content of the system.

A way of solving this problem is pretreatment of fresh material by immersion into a high osmotic pressure solution, process being known as osmotic dehydration [3]. This pretreatment partially removes water, reduces shrinkage, and allows transferring of salts/sugars and other valuable components form solution onto the surface and within the vegetal matrix. Moreover, this process maintains the characteristics of the vegetables and fresh fruit and improves the quality of processed and minimally processed fruits [3] and can have a positive impact on drying yield.

Whey, a by-product of the dairy industry resulted from cheese production, has been identified as one of the highest environmental burdens, with a very significant contribution at the total greenhouse gas emissions from the food sector [4].

Whey has a high potential to become a very good environment for pre-treating vegetables before drying with the purpose of creating a high osmotic pressure. Also the presence of lactose and salts that could be transferred from whey to vegetables is capable to provide a well balanced taste for the end product.

Although drying is one of the oldest unit operations in food industry it remains one of the most complex and least understood processes at the microscopic level, because of the difficulties and deficiencies in mathematical descriptions [5]. Drying involves simultaneous multiphase, heat, mass, and momentum transfer phenomena. Drying kinetics of fruits and vegetables were mostly studied by thin layer drying method, which refers to the fact that the material to be dried is presented as one layer of sample particles or slices [6].

Parsnip (*Pastinaca sativa* L.) is a common edible root vegetable that can be eaten raw, boiled, roasted, fried or used in soups, stews. Recent studies [7] indicated parsnip as a valuable source of a group of C17 acetylenes of the falcarinol type, which exhibit cytotoxicity against human cancer cells.

The objectives of the current study were to test the adequacy of whey (concentrated and concentrated hydrolyzed whey) as a high osmotic pressure environment in pre-treating parsnip chips and further evaluate the kinetics of drying during at different temperatures (45, 55 and 65 °C) on pre-treated parsnip chips.

MATERIALS AND METHODS

Sample preparation

Parsnip roots, bought from a local producer in Galati, Romania, were hand peeled and sliced into 2.5 mm thick disks with an electric slicer (Philips HR7762/91). Parsnip disks ranging 3.85 - 4.21 mm diameter were selected to be dried.

Whey Concentration

Whey resulted from Telemea cheese making process in the dairy pilot plant (GEA, Romania) from Faculty of Food Science and Engineering Faculty, Dunărea de Jos University from Galati, Romania was concentrated with a rising film evaporator (FT 22 Rising film evaporator, Armfield Ltd., UK) at 80 °C under vacuum. Proximate composition of concentrated whey: dry matter 11.0 %; protein 1.4 %, lactose 9.2 %, fat 0.1 %, minerals 0.1 %.

Concentrated Whey Hydrolysis

Concentrated whey was hydrolyzed with Ha-lactase 5200 (Christian Hansen, Romania), at 40 °C, during one hour, the final degree of hydrolysis being 98 %.

Three experimental setups were tested: 1) the blank sample was represented by the slices parsnip chips (B); 2) pretreated parsnip chips immersed for 30 min prior to drying into a concentrated whey solution (CW); 3) pretreated parsnip chips immersed for 30 min prior to drying into hydrolyzed concentrated whey (HW).

The moisture content prior to drying of all samples was determined gravimetric method by hot air drying oven method at 105 ± 1 °C, according to [8].

Drying

Thin layer drying of parsnip chips was performed in a computer controlled tray dryer (UOP8MKII Tray Drier, model 2014, Armfield Ltd., UK) at constant air velocity of 0.5 $m \cdot s^{-1}$ and drying temperatures of 45, 55 and 65 °C, while the ambiance air temperature ranged between 20 - 22 °C.

The fractional moisture ratio (*MR*) of drying samples at any time was calculated following equation (1):

$$MR = \frac{M_t - M_e}{M_0 - M_e} \tag{1}$$

where:

M_t - moisture content at time t (kg water/kg dry matter);

M_0 - initial moisture content (kg water/kg dry matter);

M_e - equilibrium moisture content (kg water/ kg dry matter).

$$MR = A_1 \exp\left(-\frac{\pi^2 D_{eff}}{A_2} t\right) \tag{2}$$

where: A_1 and A_2 - geometric constants; for infinite slab $A_1 = 8/\pi^2$ and $A_2 = 4L^2$, where L - the thickness of the slice if drying occurs only from one side, D_{eff} - effective moisture diffusivity (m·s^{-1}), t - time (s).

Equation (2) or Hendreson-Pabis derived from Fick`s second law of diffusion can be rearranged as a function of drying constant k (s^{-1}) as:

$$MR = \frac{M_t - M_e}{M_0 - M_e} = a\exp(-kt) \tag{3}$$

In this case D_{eff} can be estimated from drying constant k with equation (4):

$$D_{eff} = -\frac{A_2 k}{\pi^2} \tag{4}$$

The activation energy explains the influence of temperature on D_{eff} with an Arrhenius based equation:

$$\frac{D_{eff}}{D_0} = -\exp\left(\frac{E_a}{RT}\right) \tag{5}$$

where: D_0 - the Arrhenius factor or the reference diffusion coefficient at infinitely high temperature (m·s^{-1}), E_a - activation energy (kJ·mol^{-1}), R - the universal gas constant (8.314 kJ·kmol^{-1}·K^{-1}), T - temperature (K).

Mathematical modeling

Non-linear regression procedure (SAS software, version 9.1, Cary, NC, USA) was applied to estimate the parameters of equations (3) and (5). Goodness of fit was assessed by root mean square error (*RMSE*) value and corrected correlation coefficient (R^2 corrected) calculated (equations 6 and 7).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(y_{\exp}(t_i) - y(t_i, p_{i,s})\right)}{n_t - n_p}} \tag{6}$$

where: $y_{exp}(t_i)$ - experimental observations, $y(t_i,p_{is})$ - predicted values, n_t - total number of data points and n_p - number of estimated model parameters.

$$R^2_{corrected} = \left[\frac{1-(m-1)\cdot\left(1-\frac{S_{p\ regression}}{S_{p\ total}}\right)}{(m-j)}\right] \tag{7}$$

where: m - experimental observations, j - parameters and SP - sum of squares. *RMSE* (root mean square error) and is calculated by equation 7.

RESULTS AND DISCUSSION

Several compounds present in whey and their potential benefits have influenced the decision of applying this dairy by-product as an environment for parsnip osmotic dehydration. The presence of minerals such as calcium, known to retard the non-enzymatic browning in vegetables [9] was considered very important. Moreover, calcium impacts the vegetal texture and determines shrinkage of material during drying as it was demonstrated by other researches [10]. The presence of sodium and chloride ions in whey resulting from milk and/or from cheese making process is known to produce some dewatering of the tissue and, implicitly, a faster drying process. Sodium chloride also contributes to color preservation during drying and improves rehydration [11].

Nonetheless, the presence of calcium phosphate and the molar ratio calcium: phosphorus that equals almost 1 in whey, higher than in other foods, favors the absorption of calcium, which has a very important role in preventing the loss of bone mass. Traces of minerals are also present in whey and if absorbed by the vegetal tissue could boost bioavailability of many food constituents, particularly enzymes.

Lactose is the constituent that is present in the highest concentration in whey. As it was demonstrated by other researchers, dipping of plant tissue in solutions containing 15 - 30 % sugars improves rehydration of dried material, preserves its microscopic structure, protects color, reduces oxidation of carotenoids [12] and limits shrinkage of the material undergoing hot-air dehydration [9].

In the system where Ha-lactase was added and lactose was hydrolyzed only glucose and galactose are present, thereby having a sweeter taste.

The drying curves at 45, 55 and 65 °C for parsnip slices, parsnip slices pretreated with concentrated whey (CW) and hydrolyzed whey (HW) are presented in Figures 1, 2 and 3. In all cases the drying rate increase with the increase in temperature from 45 to 65 °C. As it can be noticed from the graphs higher moisture loss is obtained after approximately 30 minutes of drying at 65 °C for the slices of parsnip pretreated with concentrated whey (MR = 0.56) and hydrolyzed whey (MR = 0.58) compared with the slices with no pretreatment (MR = 0.4). Drying at 45 °C for 30 min led to a similar dehydration rate in the HW pretreated parsnip (MR = 0.82) and in the CW pretreated parsnip. Equation (3) was applied by nonlinear regression for k and a values estimation (Table 1). The k – values are increasing with temperature increase in the following order for the three analyzed systems: HW > CW > B (B- blank sample). This demonstrates that the highest osmotic pressure was created when two carbohydrates were present in solution (glucose and galactose) which led to the fastest dehydration rate, followed by the system where only lactose was present (CW).

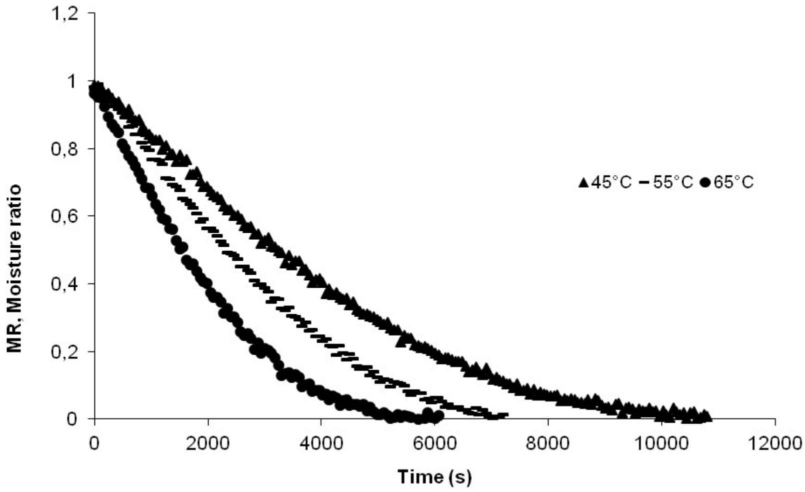

Figure 1. *Drying curves for parsnip chips (B)*

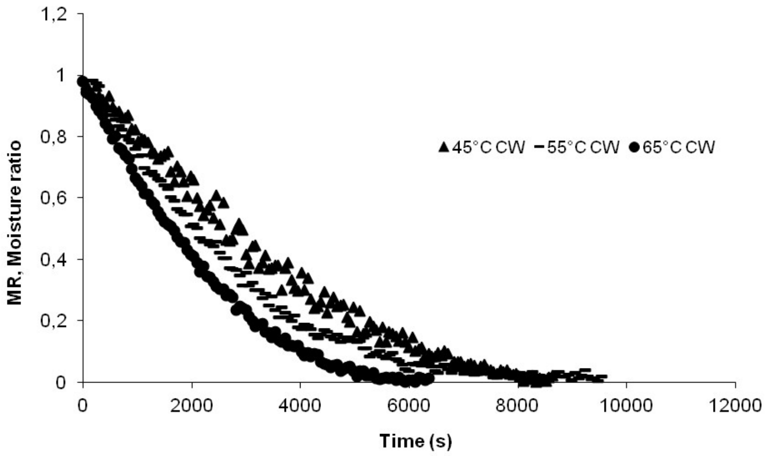

Figure 2. *Drying curves for concentrated whey - parsnip chips (CW)*

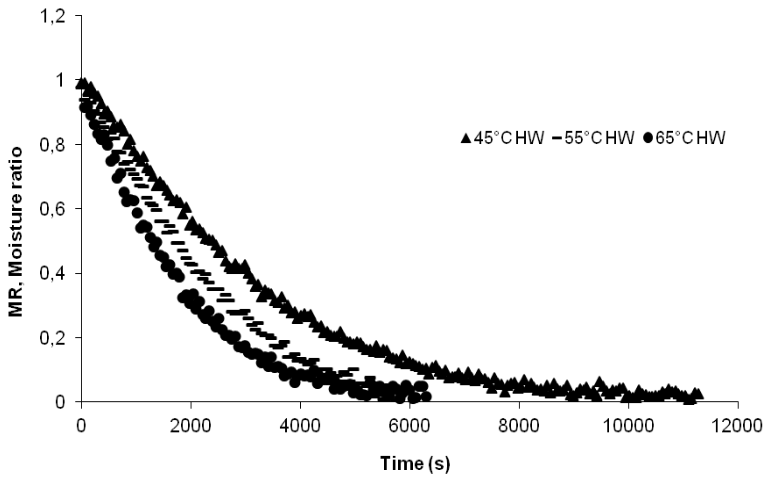

Figure 3. *Drying curves for hydrolyzed concentrated whey - parsnip chips (HW)*

For every treatment, the effective diffusion coefficient of water (D_{eff}) derived from the Fickian equation 4, for infinite slab was estimated considering a long process time (Table 1). The mean value of the initial and final sample half thickness was considered for L calculations. The highest diffusion coefficients were registered for parsnip pretreated with hydrolyzed whey that resulted in sweet chips followed by the salty parsnip chips and the lowest diffusion coefficients were obtained for the untreated parsnip chips. The values obtained in the current study are in line with other reported values for specific drying in a convective type tray dryer of vegetables (corn [13], sweet potato cubes [14], pumpkin slices [6], carrot slices [15, 16]), fruits (sliced apples [17]; plum [18], grapes [18], peach slices [19], cape gooseberry [20] and aromatic plants (parsley leaves [21], mint leaves [22]).
The activation energy was estimated from equation (5) and indicated in Table 1. The values are in line with other values reported in literature for apple pomace [23], coconut [24] and green bean [16]. The highest energy input is required by the parsnip slice per-se followed by the ones pretreated with HW and then CW.

Table 1. *Convective drying parameters for parsnip, concentrated whey-parsnip and hydrolyzed concentrated whey- parsnip chips*

Sample/ Drying temperature	Moisture diffusion parameters			
	k	***a***	D_{eff} [m^2·s^{-1}] ·10^{10}	E_a [kJ·mol^{-1}]
Parsnip (B)				
45°C	0.000276 ± 4.100 x10^{-6}	1.104 ± 0.011	1.750	31.02 ± 2.52
55°C	0.000382 ± 7.223 x10^{-6}	1.110 ± 0.014	2.421	
65°C	0.000553 ± 1.110 x10^{-6}	1.072 ± 0.014	3.505	
$R^2_{corrected}$ = 98.95; *RMSE* = 0.065				
Pretreated parsnip with concentrated whey (CW)				
45°C	0.000332 ± 6.051 x10^{-6}	1.126 ± 0.015	2.104	20.06 ± 1.65
55°C	0.000424 ± 4.436 x10^{-6}	1.127 ± 0.009	2.688	
65°C	0.000520 ± 9.002 x10^{-6}	1.063 ± 0.013	3.296	
$R^2_{corrected}$ = 99.58; *RMSE* = 0.055				
Pretreated parsnip with hydrolyzed concentrated whey (HW)				
45°C	0.000343 ± 2.604 x 10^{-6}	1.073 ± 0.005	2.174	23.89 ± 1.98
55°C	0.000471 ± 7.845 x 10^{-6}	1.057 ± 0.012	2.986	
65°C	0.000585 ± 6.706 x 10^{-6}	1.025 ± 0.009	3.708	
$R^2_{corrected}$ = 97.52; *RMSE* = 0.062				

CONCLUSIONS

Two types of parsnip snacks mildly salty and sweet were obtained by pre-treating slices of parsnip with concentrated whey. The parsnip pretreated in concentrated whey with hydrolyzed lactose (HW) had higher diffusion coefficients at all studied temperatures compared to CW. A lower activation energy input was necessary for the parsnip pretreated with concentrated whey (20.06 kJ·mol^{-1}) CW than for the HW system (23.86 kJ·mol^{-1}). Better diffusion coefficients and lower activation energies were

obtained for CW and HW pretreated parsnip compared to the parsnip without pretreatment demonstrating the usefulness of whey for osmotic dehydration.
Valorization of whey in vegetable industry could represent a smart and economically feasible solution for turning unhealthy dietary habits into healthy, nutritious ones.

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