OPTIMIZATION OF SUGAR BEET OSMOTIC DEHYDRATION BY DESIRABILITY FUNCTION APPROACH

OPTIMIZACIJA OSMOTSKOG SUŠENJA ŠEĆERNE REPE PRIMENOM POSTUPKA ŽELJENE FUNKCIJE

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ABSTRACT

Osmotic dehydration is a process of partial water removal by immersing foods, mostly fruits and vegetables, in hypertonic solutions. During osmotic dehydration, the removal of water from plant tissue is accompanied by the counter diffusion of solutes from the osmotic solution into the tissue. The purpose of this study is to determine the optimal conditions for osmotic dehydration of sugar beet cossettes using desirability function approach. The optimum operating conditions were found to be a temperature of 50 °C, a sucrose concentration of 70 % (without salt) and a treatment time of around 125 min. At this optimum point, a water loss of 46.9 % and a solid gain of 1.4 % were recorded. Relative to temperature minimization, the following optimum point values were determined: a temperature of 30 °C, a sucrose concentration of 61.4 %, a salt concentration of 8 %, and a treatment time of 240 min. In this instance, a water loss of 40.3 % and a solid gain of 0.04 % were recorded, indicating a significantly lower solid gain value compared to the first optimization results.

Key words: osmotic dehydration, sugar beet, optimization, desirability function

REZIME

Osmotsko sušenje je proces delimičnog uklanjanja vode uglavnom iz voća i povrća, potapanjem u hipertonične rastvore. U toku osmotskog sušenja, uklanjanje vode iz biljnog tkiva uvek je praćeno suprotnom difuzijom rastvorka iz osmotskog rastvora u tkiva. Cilj ove studije je određivanje optimalnih uslova osmotskog sušenja rezanaca šećerne repe koristeći pristup željene funkcije. Nezavisne eksperimentalne promenljive u ovom radu su: vreme trajanja osmotskog sušenja (30 – 240 min), koncentracija saharoze (30 – 70%, w/w), koncentracija natrijum hlorida (0 – 8%, w/w) i temperatura rastvora (30 – 50°C). Optimizacija procesa osmotske dehidracije usmerena je na pronalaženje nivoa nezavisnih promenljivih, odnosno koncentracije osmotskog rastvora, temperature i trajanja procesa, koji bi omogućili maksimalan gubitak vode uz istovremeni najmanji mogući priraštaj suve materije. Primenom metode željene funkcije utvrđeno je da su optimalni uslovi rada temperatura 50°C, koncentracija saharoze 70%, koncentracija soli 0% i vreme trajanja sušenja oko 125 minuta. Na ovim optimalnim uslovima, gubitak vode i priraštaj suve materije su 46,9% i 1,4%, respektivno. Da bi se smanjili energetske zahteve procesa osmotskog sušenja šećerne repe, izvršena je optimizacija sa izborom pojedinačne željene funkcije za minimizaciju temperature, tj. odabrana je minimizacija temperature u postupku optimizacije. U ovom slučaju utvrđeno je da gubitak vode iznosi 40,3%, dok vrednost priraštaja suve materije značajno niža u odnosu na rezultate prve optimizacije i njegova vrednost je 0,04%. Na ovim optimalnim uslovima, eksperimentalne vrednosti temperature, koncentracije saharoze, koncentracija soli i vremena sušenja iznose 30°C, 61,4%, 8% i 240 minuta, respektivno.

Ključne reči: osmotsko sušenje, šećerna repa, optimizacija, željena funkcija.

INTRODUCTION

Dietary fibres are the primary structural components of plant cell walls, and thus can exert positive physiological impacts on the health of people. The sugar beet (*Beta vulgaris saccharifera* L.) is a good source of dietary fibres necessary in human nutrition and can be used as supplement to bran (e.g. in breakfast cereals) as well as a substitute for sugar. It typically contains hemicelluloses, pectin, cellulose, proteins, sucrose, lignin, soluble mineral matter and insoluble mineral matter (Broughton *et al.*, 1995). The drying of dietary fibres is necessary in order to obtain a longer shelf life and a substantial volume reduction. Drying is one of the oldest methods of food preservation, and it may be the source of undesirable changes in the quality of dried products. Sugar beet fibers are dried by hot air or microwaves (Jokić *et al.*, 2005a, Jokić *et al.*, 2005b, Jokić *et al.*, 2013).

Osmotic dehydration, due to its energy and quality related advantages, is popular as a complementary processing step in the chain of integrated food processing. Osmotic dehydration represents a simultaneous counter-current mass transfer process

(Lenart and Flink, 1984). In addition, a leaching of the product's own solutes (sugar, organic acids, minerals, vitamins, etc.) also occurs, which is quantitatively negligible compared with the first two transfers, yet essential regarding the final products composition (Dixon and Jen, 1977).

The water loss of the material and accompanying changes in its chemical composition depend upon a number of factors such as the type of osmotic substance, temperature and concentration of osmotic solution, dehydration time, size and geometry of material, solution-to-material mass ratio, agitation and etc.

The influence of the concentration and temperature of the osmotic solution has been studied extensively, and it has been shown that the rate of osmotic dehydration increases with the rise of both parameters. The choice of the osmotic solution plays a very important role, and the specific effects of individual solutions must be taken into account. The choice is mainly dependent on the price and availability of osmotic solutions. Saccharides (sucrose, glucose and fructose) are most commonly used in the osmotic dehydration of fruits, whereas salts, primarily sodium chloride, are used in the osmotic dehydration of fruits. However, it has been observed that a combination of

sucrose and salt, such as sodium chloride, enhances osmotic dehydration more than the use of solutions containing these components individually (Sacchetti et al., 2001).

In the optimization of various technological processes, such as osmotic dehydration, several response variables describing the quality characteristics and performance of the systems are to be optimized (i.e. some to be maximized and some to be minimized). These responses are competing, and thereby improving one may exert an opposite effect on the other. The following approaches have been used to solve this problem: a constrained optimization procedure, superimposing the contour diagrams of the different responses, and using a desirability function that combines all the responses into one measurement (Costa Ribeiro et al., 2016).

The main benefit of using desirability functions for optimization is the possibility of comparing responses that have different scaling, whereas the transformation of different responses to one measurement is simple and quick. It is based on the idea that the “quality” of a product or process that has multiple quality characteristics, with one of them outside of some “desired” limits, is completely unacceptable. The method finds operating conditions of selected variables or factors that provide the “most desirable” response values. Depending on whether a particular process response is to be maximized or minimized, different desirability functions can be used. After desirability values are calculated for each response, they are combined into a single desirability index D by calculating their geometric mean. Weighting can be applied by assigning the importance of optimizing to each response variable (Eren and Kaymak-Ertekin, 2007).

The purpose of this study is to determine the optimal conditions for osmotic dehydration of sugar beet cossettes in combined solutions (sucrose and sodium chloride) using desirability function approach.

Nomenclature:

M	– moisture content (g)
S	– solids content (g)
WL	– water loss (%)
SL	– solid gain (%)
W	– sample weight (g)
d	– individual desirability function
D	– overall desirability function
Y	– response
L	– lower values of responses
U	– upper values of responses
G	– goal (target) values of responses
v	– relative importance of responses

Subscripts

0	– fresh sample
f	– osmotically
i	– number of responses
s	– exponent of significance

MATERIAL AND METHOD

The osmotic dehydration of sugar beet cossettes was carried out in a shaker fitted inside a thermostatically controlled chamber. In each of the experiments conducted, fresh osmotic solutions were used. At each sampling time, cossettes were taken out and washed with fresh running water to remove excess solution. Moisture and dry matter content of the samples were determined by drying at 70 °C for 24 h. A detailed explanation

of the experimental procedure can be found in the literature (Jokić et al., 2007).

Water loss (WL) was expressed as the net loss of water from fresh sugar beet cossettes after osmotic treatment relative to the initial sample weight, whereas solids gain (SG) was considered as the net uptake of solids by osmosed samples based on the initial sample weight (Le Marguer, 1988):

$$WL(\%) = \frac{M_0 - M_f}{W_0} \cdot 100 \quad (1)$$

$$SG(\%) = \frac{S_f - S_0}{W_0} \cdot 100 \quad (2)$$

The process variables and their ranges were as follows: time (30–240 min); sucrose concentration (30–70 %, w/w); sodium chloride (salt) concentration (0–8 %, w/w) and temperature (30–50 °C).

RESULTS AND DISCUSSION

Response surface methodology (RSM) was used for the process modelling, whilst the experimental data of the responses, water loss and solid gain, were fitted by a second-degree polynomial model. Detailed statistical parameters values indicating the adequate modelling of osmotic dehydration process of sugar beet cossettes by applying RSM can be found in the literature (Jokić et al., 2007).

The results of RSM obtained in the form of second-degree polynomial models for water loss and solid gain can be used for the optimization by desirability function approach.

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Depending on whether a specific response Y_i is to be maximized or minimized, different desirability functions $d_i(Y_i)$ can be used (Derringer and Suich, 1980). Provided L_i , U_i and G_i are the lower, upper, and goal (i.e. target) values respectively and the desire for selected response is to be maximized, its individual desirability function, with the exponent s , determines how important it is to hit the target value. For $s = 1$, the desirability function increases linearly towards G_i which denotes a large enough value for the response; for $s < 1$, the function is convex, and for $s > 1$, the function is concave:

$$d_i(Y_i) = \begin{cases} 0 & \text{for } Y_i(x) < L_i \\ \left(\frac{Y_i(x) - L_i}{G_i - L_i} \right)^s & \text{for } L_i \leq Y_i(x) \leq G_i \\ 1 & \text{for } Y_i(x) > G_i \end{cases} \quad (3)$$

When a response is minimized, at that point its individual desirability function, with G_i denoting a small enough value for the response, is of the following form :

$$d_i(Y_i) = \begin{cases} 1 & \text{for } Y_i(x) < G_i \\ \left(\frac{Y_i(x) - U_i}{G_i - U_i} \right)^s & \text{for } G_i \leq Y_i(x) \leq U_i \\ 0 & \text{for } Y_i(x) > U_i \end{cases} \quad (4)$$

Subsequently, when individual desirability values are computed for each response variable, by calculating their geometric mean, they are combined into the single desirability index D . Further refinements to the weighting can be applied by assigning a range of numbers to every response according to the importance of variable optimisation. The relative importance of a response is indicated with a number, which might typically be an integer in the range from one to five, with the highest number indicating the greatest importance and the lowest indicating the least. The final desirability index D is calculated as follows:

$$D = (d_1^{v_1} \times d_2^{v_2} \times d_3^{v_3} \times \dots \times d_n^{v_n})^{1/\sum v_i} = \left(\prod_{i=1}^n d_i^{v_i} \right)^{1/\sum v_i} \quad (4)$$

In the present study, two scenarios were investigated. The first scenario was with two optimizing variables WL and SG. Therefore, desirability functions were developed for this scenario, and the water loss was set to achieve the maximum values, whereas the solid gain was simultaneously set to the lowest values. In the second scenario, additional variable has been introduced, i.e. the temperature was minimized in order to reduce energy requirements of the osmotic dehydration process.

The application of desirability function method for simultaneous water loss maximization and solid gain minimization results in a decreased processing time with increasing temperature. All other parameters were selected to be within the range as the second-degree polynomial models for water loss and solid gain can be valid within the experimental range. The best solution indicated the overall desirability function value of 0.880, whereas the individual desirability functions were 0.943 and 0.822 for water loss and solid gain, respectively. At this optimal point, a sucrose concentration of 70 % w/w and no salt concentration were recorded.

The hand temperature was at the upper value of the experimental range of 50 °C. The value of water loss was 47 %, whereas the solid gain value was 1.4 %. The relatively high values of solid gain indicate that flavour difficulties are to be expected, so sensory analysis should be included in prospective future experimental investigations. The time needed to achieve this optimal value of water loss and solid gain is around 125 minutes, suggesting that the process could be shortened.

The influence of sucrose concentration and immersion time on the overall desirability function in the first scenario is shown in Fig. 1. An increase in the sucrose concentration indicates a rise in the desirability function values during the whole osmotic dehydration process (as it can be seen in Fig. 1). The desirability index increases with an increase in the sucrose concentration up to 50 %, because the water loss is increased in a shorter process time up to 150 minutes. This is the reason why there is a rapid growth in the desirability index at the beginning of osmotic dehydration.

The desirability function indicates higher values at the upper end of the experimental temperatures as the water loss increases with the rise in temperature. Higher temperatures can change plant cell membrane structure, so it becomes more permeable to

water molecules that come out of the product, while decreasing the viscosity of the osmotic solution (which causes less resistance to water diffusion on the product surface) (Saputra 2000, Contreras and Smyral, 1981).

The porous structure of sugar beet tissue also contributes to the increase in water loss. Namely, the air from the porous structure of the tissue is released at higher temperatures, whereas the loss of water, i.e. the desirability index rise, increases due to an increase in the contact surface of the tissue and the osmotic solution.

Fig. 1. Influence of sucrose concentration and immersion time on the overall desirability at a temperature of 50 °C in an osmotic solution (without salt)

The solid gain also increases during the osmotic process at higher sucrose concentrations, especially during prolonged dehydration times up to 240 minutes. This may be accounted for by the loss of permeability of the cell membrane during the prolonged processing time. Consequently, an increase in the solid gain can occur accompanied by a decline in the desirability index values. For achieving the overall desirability function higher than 0.850, the processing time has to be within the range from 80 to 135 minutes.

The dry matter increases during the osmotic process and with a rise in the temperature of osmotic solution. As a result, a decrease in the desirability function values was observed. Higher temperatures increase the permeability of the cell membrane, so in addition to an increase in the water loss, a simultaneous increase in the solubility of plant tissue also occurs, i.e. the dry matter content or solid gain increases to some extent (Lazerides et al., 1997). At a temperature of 50 °C, there is a decrease in the solid gain which can be accounted for by the total loss of permeability of the cell membrane. Therefore, at higher temperatures water leaves the cell together with cellular juices and the dry matter of the cosettes decreases. However, the molecules of sucrose, owing to their size, are slower in penetrating the plant tissue.

Working at higher temperatures exerts evident negative effects on the product quality and energy costs. This is the reason why the second optimization scenario encompassed the minimization of temperature values.

In this scenario, the overall desirability function was near the values obtained for the first scenario amounting to 0.893. Moreover, the individual desirability function for temperature was 1, indicating a lower value of the experimental range, i.e. 30 °C. Conversely, the individual desirability function for water loss and solid gain were 0.743 and 0.951, respectively. The

values of the individual desirability functions were lower for the water loss, whereas were shown to be higher for the solid gain. At this optimal point, the solid gain recorded was 0.4 %, which 3.5 times lower compared to the first scenario. The water loss values simultaneously decreased from 47 % in the first scenario to 40 % in the second. The sucrose and sodium chloride concentrations were 62 and 8 %, w/w, respectively.

Fig. 2. Influence of sucrose concentration and immersion time on the overall desirability at a temperature of 30 °C and a sodium chloride concentration of 8 %, w/w

Fig. 3. Influence of sucrose and sodium chloride concentrations on the overall desirability at a temperature of 30 °C and an immersion time of 240 minutes

The influence of sucrose concentration and immersion time on the overall desirability function employed in the second scenario of optimization is shown in Fig. 2. An evident decrease in the temperature values from 50 °C to 30 °C results in the prolonged processing time (around 240 minutes) in order to achieve higher values of the overall desirability function. Relatively high values of the overall desirability function can be achieved even in a shorter time and at lower sucrose concentrations, due to fact that sodium chloride increases the osmotic pressure of the solution compared to the sucrose.

An increase in the sodium chloride concentration leads to a higher solid gain values so the desired overall desirability function values can be attained for lower sucrose concentrations

(Fig. 3). For higher sucrose and lower salt concentrations, the solid gain is small so its individual desirability function could be high. Conversely, the individual desirability function for water loss tends to be lower because low osmotic pressure of the solution. At high sucrose concentrations, a crust of accumulated sucrose molecules can be formed around beet tissue, hindering the rapid intensification of solid gain. However, higher salt concentrations can cause an increase in water loss as well. The reason for increased water loss at higher sodium chloride concentrations can be found at the cellular level. Sucrose and sodium chloride can pass through the cellular membrane, whereas only salt can diffuse through cytoplasmic membrane (Isse and Schubert, 1992). Consequently, the overall desirability index is increased, and the maximal values of desirability index are achieved with sucrose concentrations ranging from 60 to 70 %, w/w and salt concentrations ranging from 6 to 8 %, w/w.

ACKNOWLEDGEMENT: This research was financially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Project No. TR-31002).

CONCLUSION

The desirability function approach for sugar beet osmotic dehydration optimization was found to be very useful. The results obtained suggest that higher temperatures can result in shorter dehydration time. However, working at higher temperatures exerts negative effects on the product quality and energy costs. Furthermore, the desirability value of the second solution was greater than the first, and thus the factor level combinations obtained when using the second solution were selected as the optimum.

For further optimization of this process, a sensory analysis accompanied by detailed energy requirements should be performed. Additional economic analyses could be carried out with regard to the cost of solutes and the possibility of using spent osmotic solutions as raw materials for bioethanol production.

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Received: 27. 02. 2018.

Accepted: 14. 03. 2018.