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Influence of Edible Coating and Process Conditions on The Osmotic Dehydration of Carrot Slices

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Abstract

Optimization of process parameters in osmotic dehydration is critical to achieve desired levels of water removal and solid uptake. To minimize the solid gain, food materials are coated with edible films prior to drying. In this study, the effects of solution temperature (25°C, 35°C and 45°C), sugar solution concentration (40%, 50% and 60%) and edible film coatings on solid gain (SG) and water loss (WL) of osmotically dehydrated carrot slices were investigated. Solid gain and water loss rates after osmotic dehydration were determined and dehydration efficiency index values were calculated. It is observed that WL and SG values increase with the increasing temperature and solution concentration. The solid permeability of cornstarch coating was lower compared to plum coated and non-coated samples. Weight loss of dehydrated carrot slices coated with cornstarch were higher than the non-coated ones. Cornstarch based edible coatings did not have a negative effect on water loss while plum based edible coatings caused the water loss to decrease. Optimum mass transfer rates for water and solids were achieved at 25°C with a solution concentration of 60%. Highest dehydration efficiencies recorded were of starch-coated samples at all process parameters. Plum coating showed a slight improvement against non-coated samples at optimum process parameters.

Keywords: Dehydration effiency, edible coating, osmotic dehydration, solid gain, water loss

1. Introduction

Drying is an ancient and basic operation used to preserve food materials for further consumption and to enhance food safety. In conventional drying process, food material is subjected to extensive heat energy and as a result sensorial, physical, and nutritional properties of the food material are affected adversely [1]. Non-thermal novel processes are being developed and optimized to overcome this obstacle. Osmotic dehydration, one of the non-thermal water removal processes, can be defined as partially removal of water by immersion of the food material into a hypertonic solution. Water is removed from the product without changing its phase up to a level of 50% and a minimally processed food material is obtained. Due to non-thermal characteristics of osmotic drying, nutritional and sensory losses can be kept at minimum while deterioration reactions such as browning or oxidation are inhibited [2-4].

During osmotic dehydration, a pressure gradient is formed in solution medium across the cell surface, thus water molecules move through surface of food material to the solution and simultaneously solutes are transferred into the tissue [5]. Materials used to formulate the osmotic solution can be selected from a wide range of options such as sugars like glucose, sucrose and fructose or salts or a combination of these. Type of the food material to be dried is critical in the selection of osmotic solution due to the potential sensorial effect of the solute uptake. Therefore, the prominent considerations in osmotic dehydration are the type and extent of solute as this selection directly affects both the properties of food material and the rate of operation [6,7].

During the osmotic dehydration, water loss of the food material is the main interest of the operation; besides this preferred case, solute uptake is the undesirable side effect due to mainly sensorial changes and also the formation of a surface barrier by solids which reduces the water loss [8,9]. Thus, it is critical to inhibit excessive solid uptake without creating a negative effect on the rate of water loss. Adjustment of the process parameters such as temperature and duration is essential but not sufficient to lower the solid uptake to a desired level. Using edible coatings to lower solute uptake without blocking water loss of the food material can be considered as an efficient improvement in the process [10]. Edible coatings are developed with the use of bio-based polymers such as starches, proteins, lipids, gums or cellulose derivatives that are made from various agricultural commodities. Edibility, biocompatibility and barrier properties are the main features of edible coatings [11,12]. Use of edible coatings offers the potential to reduce the unfavorable effects of osmotic dehydration [13,14].

The objective of this study was to investigate the effects of starch and plum based edible coatings on osmotic dehydration of carrots (*Daucus carota* L. ssp. *sativus*) and to examine the effects of process parameters such as temperature and solution concentration on the dehydration kinetics.

2. Materials and Methods

2.1. Materials

Carrot (*Daucus carota* L. ssp. *sativus*) samples were osmotically dehydrated in this work. Samples were purchased daily from a local market in Istanbul. Samples were selected to ensure minimal variation and refrigerated at 4 °C until experiments. Edible films used in the study were prepared with cornstarch (commercial) and damson plum (*Prunus domestica* subsp. *insititia*). Sucrose (commercial sugar) was used as the osmotic agent.

2.2. Materials preparation

Carrot samples were cut into slices with a thickness of 0.5±0.1 cm and a diameter of 2.0±0.1 cm after peeling. Sucrose solutions (300 g. each) with the concentrations of 40%, 50% and 60% w/w were prepared in 600 ml beakers with deionized water. Product/solution ratio was adjusted to 1:10 (weight basis) to avoid any dilution in osmotic media.

2.3. Coating treatments

Cornstarch solution (3% w/w) was prepared by heating and stirring the water/starch mix at 80°C and 90 °C, for 15 minutes at each temperature. Solution was cooled to room temperature and carrot samples were immersed in solution for 3 minutes. Coating was fixed on samples by heating at 70°C for 25 minutes in a convection oven. Plum coating solution was prepared by mashing the peeled fruit and diluting to 10° Brix with deionized water. Carrots were immersed in solution for 3 minutes and the coating fixed by heating at 70°C for 60 minutes.

2.4. Osmotic dehydration treatment

Coated and non-coated carrot samples submerged in osmotic solutions and kept in contact with the solution during the dehydration period by using a form of plastic cage. Processes carried out for 210 minutes (3.5 h) at three levels of temperatures. Solution-sample containing beakers placed in incubators during dehydration process at 25, 35 and 45 °C to ensure uniform temperature distribution in experimental units. Immediately after osmotic process, carrot samples were removed from solution and blotted with adhesive paper to remove residual sugar solution. Samples weighed and moisture contents were calculated. A portion of the osmotically dehydrated and non-treated carrot samples were oven-dried by the standard method to calculate the initial and final dry matter [15].

Weight reduction (WR), water loss (WL) and solid gain (SG) data were calculated to indicate overall mass exchange between sample and solution. Dehydration efficiency index (WL/SG ratio) was also used to indicate the efficiency of process. The mass amount of solids leaching from the product (sugars, acids, vitamins and minerals) assumed to be negligible [16]. Following equations were used to calculate mass balances during osmotic dehydration [17,18]. Weight reduction is the overall weight loss during the operation, solid gain is the amount of solutes transferred to samples and water loss is the total amount of water removed from samples with respect to initial weight of the sample.

$$WR = \frac{w_i - w_f}{w_i} \times 100 \quad \textbf{(1.1)}$$

$$SG = \frac{w_{sf} - w_{si}}{w_i} \times 100 \quad \textbf{(1.2)}$$

$$WL = \frac{w_{wi} - w_{wf}}{w_i} \times 100 \quad \textbf{(1.3)}$$

Where w_i is initial weight of the sample, w_f is the weight of the sample after osmotic dehydration. w_{sf} and w_{si} are the initial and final dry matter content of samples and w_{wi} and w_{wf} are the initial and final amount of water in samples.

2.5. Statistical analysis

Experiments were conducted in triplicates for each level of parameters and variations among the replicates were given as error bars. Statistical analyzes were carried out using *MINITAB 17* software. Variations among the means of treatments were calculated to perform analysis of variance, and the means were compared according to Tukey and Fisher's tests to determine significant differences.

3. Results and discussion

Rates of water loss and solid gain are the main responses of an osmotic dehydration process. Therefore, the remarks on these values explain the influence of different factors applied in the process. The extent of water loss and solid gain were calculated and shown in Tables 1 and 2, respectively. Levels of each factor (temperature, concentration and coating treatment) were given as they have substantial impact on mass exchange values.

Table 1. Effects of temperature, concentration and coating treatment on the water loss of carrot during osmotic dehydration.

Temp. (°C)	Conc. (%)	Non-coated	Starch Coated	Plum Coated
25	40	45.09 ± 1.18^{A}	45.00 ± 1.03^{A}	37.79 ± 0.49^{B}
	50	55.41 ± 0.52^{A}	55.59 ± 0.68^{A}	51.10 ± 0.27^{B}
	60	60.01 ± 1.06^{B}	65.17 ± 0.01^{A}	61.28 ± 0.35^{B}
35	40	49.09 ± 0.03^{A}	49.60 ± 0.58^{A}	36.70 ± 0.33^{B}
	50	57.66 ± 0.47^{B}	61.83 ± 1.05^{A}	51.56 ± 1.36^{C}
	60	65.63 ± 0.64^{B}	68.15 ± 0.13^{A}	59.02 ± 0.78^{C}
45	40	51.60 ± 1.60^{A}	51.85 ± 1.05^{A}	39.93 ± 0.37^{B}
	50	62.49 ± 0.96^{A}	61.34 ± 0.81^{A}	54.48 ± 0.12^{B}
	60	69.80 ± 0.92^{A}	68.88 ± 0.49^{A}	63.85 ± 0.27^{B}

*Results are expressed as the Means ± Standard Deviation for triplicates
**Means that do not share a capital letter in the same line are significantly different at p≤0.05 according to Tukey and Fisher tests.

Table 2. Effects of temperature, concentration and coating treatment on the solid gain of carrot during osmotic dehydration.

Temp. (°C)	Conc. (%)	Non-coated	Starch Coated	Plum Coated
25	40	6.09 ± 0.29^{A}	5.32 ± 0.30^{A}	5.65 ± 0.92^{A}
	50	7.29 ± 0.48^{A}	6.15 ± 0.03^{B}	6.60 ± 0.65^{B}
	60	7.57 ± 0.54^{A}	6.47 ± 0.28^{B}	7.15 ± 0.02^{AB}
35	40	7.80 ± 0.26^{A}	6.42 ± 0.21^{B}	6.63 ± 0.27^{B}
	50	8.72 ± 0.57^{A}	6.61 ± 0.08^{B}	6.94 ± 0.09^{B}
	60	8.77 ± 0.49^{A}	6.89 ± 0.05^{B}	7.18 ± 0.21^{B}
45	40	8.15 ± 0.82^{A}	6.48 ± 0.61^{B}	8.20 ± 0.47^{A}
	50	8.74 ± 0.40^{A}	7.11 ± 0.33^{B}	8.73 ± 0.23^{A}
	60	8.89 ± 0.42^{A}	7.30 ± 0.42^{B}	8.78 ± 0.42^{A}

*Results are expressed as the Means ± Standard Deviation for triplicates
**Means that do not share a capital letter in the same line are significantly different at p≤0.05 according to Tukey and Fisher tests.

3.1. Effects of process temperature

Increase in the process temperature results in increased values of water loss and solid gain for each type of coating. Although the increase caused by temperature rise in water loss is significant, increase in the solid gain seemed to be more effective, especially from 25 to 35°C for non-coated and starch coated samples. The effect of temperature increase from 25 to 35°C was relatively poor on plum coated samples regarding both water loss and solid gain. Diffusion is a temperature dependent process, thus the increase in water loss from the product and the diffusion of osmotic agent into the product would be enhanced by the increase in the temperature due to lower viscosity of the medium and swelling of cell membranes [19]. Increase of water loss for starch-coated samples was around 10%, which was relatively higher than plum coated or non-coated samples regarding the temperature increase from 25 to 35°C. Solid gain, on the other hand, seemed to increase in a higher manner from 25 to 35°C. The rate of this increase was very high at lower concentrations, which were 28% for non-coated, 21% for starch coated and 17% for plum coated samples at 40% sugar concentration. Another apparent change in solid gain with temperature was recorded for plum coated samples, the rises were around 23% when the temperature increased from 35 to 45°C for all concentrations. As a general perspective of osmotic dehydration, mass transfer rates increase with temperature, but over 45°C browning and flavor change takes place and over 60 °C tissue characteristic alter remarkably resulting the solids to impregnate into the intercellular spaces of the food material. Thus, the optimum process temperature depends on the food material [20]. In the case of green beans, for instance, 20°C is considered preferable compared to 40 °C [21].

3.2. Effects of solution concentration

The increase in sugar concentration results in increased percentage of water loss for all types of coatings at all temperatures. As seen in Table 1, increasing the concentration from 40 to 50% results in a high increase in water loss. This value was approximately 20% for non-coated and starch coated samples. For plum coated samples, increase in water loss boosts up to 40%. Besides, when the concentration increased to a level of 60%, the rise in water loss is roughly half the previous value. This is most likely because the concentration gradient between the food material and hypertonic solution reaches to a maximum and the further increase in concentration would have relatively lower effect on mass transfer. Similar trend was observed for solid gain, which can be seen in Table 2. Increase in solid gain was observed to be between 4-19% for different temperatures and types of coatings when the concentration was increased to 50%. A lower rise was seen when the concentration was increased to 60%, between approximately 1% and 8%. Increased concentrations apparently increase the sugar uptake and promotes the formation of a solid layer across the food product-osmotic medium interface, which decelerates the mass transfer, for both solids and water. Suppression of solid uptake seems to be more intense regarding the molecular size difference between sugar and water. Increase in water loss and solid gain by the change in solution concentration also determined in various other studies. Calculation of modelling parameters showed an increase in mass transfer rates for the osmotic dehydration of cherry tomato [16] and apple [22] at higher concentrations, which is referred to the cellular response of the food material to the osmotic pressure increment.

3.3. Effects of edible coatings

Edible coatings have a significant effect on the mass transfer during osmotic dehydration of food materials. Reducing the solid uptake is the main interest of coating samples but the reduction of water loss is the negative response of the process. Experimental results show that edible coatings substantially reduce solid uptake during the dehydration process. It can be seen in Table 2, that percentage of solid gain was lower for coated samples than non-coated samples at all parameters except 45 °C. Non-coated and plum coated samples seem to have similar rates of solid gain at 45 °C, which were higher than starch coated samples. Concurrently, edible coatings have a considerable effect on water loss, which can be a critical limitation. There seemed to be no significant difference between non-coated and starch coated samples for most of the cases. For sugar concentration of 60%, starch coated samples showed a higher water loss than non-coated samples at 25 and 35 °C. Similar effects of edible coatings on water loss and solid gain were reported by various authors. Garcia et. al. [23] showed that papaya samples with chitosan based coatings have lower solid gain and higher water loss values, because of the blockage of solute penetration by the solids accumulated on the surface of the coating. Also, Jalaee et. al. [17] stated that carboxyl-methyl cellulose, low-methoxyl pectinate and corn starch coatings on apple samples had a beneficial effect on reducing solid gain without having much impact on water removal. On the other hand, plum coated samples showed a relatively lower water loss rates. This may be a result of redundant heat used for fixation of coating onto samples. Coating solution had a low viscosity and a high water content as described previously in section *2.3*, this resulted in the need for a longer period of surface drying to avoid leakage of coating. The fixation period of the coating caused a mild initial surface dehydration, thus affecting the rate of water loss adversely. Consequently, percentage of water loss values of plum coated samples were slightly lower than non-coated and starch coated samples.

3.4. Dehydration efficiency index

Dehydration efficiency index is the term used to express the extent of solid gain relatively to water loss of the sample. High ratio of water loss to solid gain (WL/SG) means the process is focused on dehydration with minimal solid uptake, while low ratios mean the process targeted to extensive solid gain for operations like salting or candying [24,25]. The WL/SG ratio can accurately reveal the influence of process conditions and coating treatments. In the case of osmotic dehydration of fruits and vegetables, it is mostly aimed to achieve high levels of water loss and minimal solute uptake. Therefore, high DEI values are preferred. DEI values observed in this work are given in Figure 1 to illustrate the effects of temperature and solution concentration regarding to different coating treatments.

Coated and non-coated samples shows similar behavior against changes in process parameters. Highest values of DEI were observed at lowest temperatures (25°C) for each coating and each concentration. In addition, it can be seen in Fig. 1 that the solution concentration has a favorable effect at each process parameter; highest sugar concentration treatment in this study (60%) has the highest proportional difference between water loss and solid gain values. Correspondingly, Lazarides et. al. [26] stated that the largest difference between moisture diffusivity and soluble solids diffusivity for the osmotic dehydration of Granny Smith apples and white potatoes was observed at the lowest process temperature (20 °C) with the highest solution concentration (65%). It is also shown in a study conducted on a model food (agar gel) that the gap between water loss and solid gain values expands in a positive manner with increasing concentration, thus a dewatering situation occurs rather than a candying situation [27]. Effects of edible coatings on mass transfer kinetics of carrot samples can be clearly seen by the use of DEI data. As previously stated, effects of coatings individually on water and solids transfer were dissimilar, thus the dehydration efficiency index shows a more prominent outcome as it is the ratio of these mass transfer variables. Starch coated samples seem to have the highest value of DEI as seen in Fig. 1. Min. and max. DEI values for starch were 7.73 and 10.07, which observed at 35 °C with 40% concentration and at 25 °C with 60% concentration, respectively. To highlight the difference between the coating treatments, WL/SG values at the optimum process temperature (25 °C) were given in Figure 2.

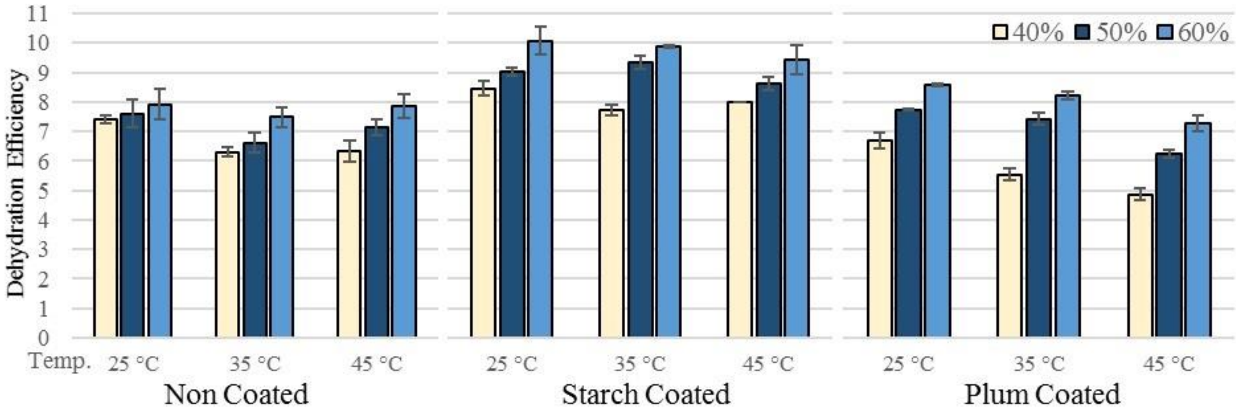

Figure 1. Effect of process conditions on dehydration efficiency index of non-coated, starch coated and plum coated samples.

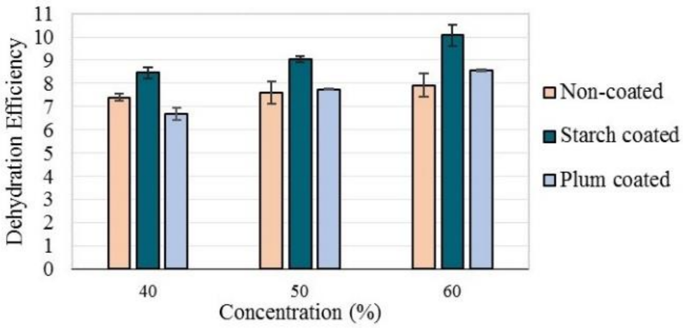

Figure 2. Effect of coating treatments on dehydration efficiency index of carrot samples at 25°C.

Increase in concentration does not seem to have a significant effect on non-coated samples, regarding the DEI at 25 °C. On the other hand, plum coated samples give better values when the concentration increased to the optimum level (60%), increasing from 6.69 to 8.57, while non-coated samples remain at 8.09. These outcomes suggest that it would be suitable to use plum coating at higher osmotic pressures to achieve a practical dehydration efficiency.

4. Conclusion

Increase in studied process parameters, temperature and solution concentration lead to a significant increase in water and solids diffusivity. However, temperature had an inverse effect on dehydration efficiency regarding the increase in solid gain of sample thus causing the lowest temperature (25 °C) to be the most efficient. Besides, highest water loss/solid gain ratio was obtained at the highest solution concentration (60%). Selecting the adequate solution concentration ensures the aimed increase in water loss without an excessive rise in solute uptake. It is also found that, use of edible coatings can significantly inhibit solute uptake during osmotic dehydration without critically affecting the water loss of samples. In this study, cornstarch coated samples showed an excellent behavior in terms of solid and water diffusion. Solid gain values of coated samples dropped significantly without having any impact on water loss in comparison with non-coated samples. On the other hand, application of plum coating seemed to have affected water loss adversely while inhibiting solute uptake. Considering the optimum process parameters, plum coating showed a slight improvement against non-coated samples. Nevertheless, starch coating offers better values of water loss and solid gain compared to plum coating.

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Author's Contributions

Osman Yağız Turan: Drafted and wrote the manuscript, performed the experiment and result analysis.
Ebru Fıratlıgil: Assisted in analytical analysis on the structure, supervised the experiment's progress, result interpretation and helped in manuscript preparation.

Ethics

There are no ethical issues after the publication of this manuscript.

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