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Mass transfer rate and osmotic treatment efficiency of peaches

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Abstract. The highest-quality peaches [*Prunus persica* (L.) Batsch] are cultivated in areas with sunny summers, therefore the territory of the Autonomous Province of Vojvodina is a favourable region for their production. Peaches are usually consumed fresh, canned, or dried and represent a great source of the essential nutrients. Osmotic dehydration is a well-known preservation method that relies on mild temperatures and requires low energy. Research conducted at the Faculty of Technology Novi Sad has introduced sugar beet molasses as an efficient osmotic solution for drying various food samples. In this research, peach samples were osmotically treated in sugar beet molasses, and the goal was to investigate the impact of different solution concentrations, temperatures, and immersion time on the mass transfer rate and the efficiency of treatment. The results have shown that the mass transfer rate during the osmotic treatment of peach samples in sugar beet molasses was the most intensive at the beginning of the process, at the highest solution concertation, and at the highest temperature. In accordance with the results, diffusion occurred most rapidly during the first three hours of the process; therefore, processing time can be reduced.

Keywords and phrases: osmotic drying, sugar beet molasses, weight reduction, dehydration efficiency index, PCA, correlations

1. Introduction

Peaches are aromatic fruits with a specific, enjoyable, sweet taste, high organoleptic properties, nutritional values, and many commercial varieties (*Mihaylova et al.*, 2022; *Veerappan et al.*, 2021; *Lin et al.*, 2020). The Autonomous Province of Vojvodina is an advantageous region for the production of peaches due to good climate conditions (*Bulatović et al.*, 2017). Peaches are highly perishable and need preservation techniques to improve their shelf life (*Ayub et al.*, 2021).

Numerous processing methods can be used to preserve fruits; however, drying is the oldest form of food preservation, mainly because of water removal from the food samples, which slows down the action of the microorganisms (*Najafi et al.*, 2014; *Chavan & Amarowicz*, 2012). Osmotic dehydration, as one of the popular drying methods, attracts attention due to enhanced drying efficiency and reduced drying time (*Kutlu*, 2021; *Sakooei-Vayghan et al.*, 2020). Osmotic treatment involves preserving the freshness of plant and animal samples by immersion in an osmotic solution, enabling the flow of water molecules from the samples to an osmotic medium, and, to a lower extent, it transfers solutes from the solution into the samples, resulting in intermediate moisture products with acceptable organoleptic properties containing lower water activity, solute gain, and water loss (*Ramya & Jain*, 2017; *Ahmed et al.*, 2016). The gain of solids from the solution by the food leads to enriched foods by incorporating in the food matrix the compounds from the osmotic solution; for this reason, the selection of the proper hypertonic medium is crucial for the quality improvements of the dried product (*Abrahão & Corrêa*, 2021; *Shete et al.*, 2018).

Sugar beet molasses, a side-product of the sugar industry, has been confirmed as a satisfactory osmotic medium due to its technological effectiveness in water removal and its rich nutritional composition and low cost (*Nićetin et al.*, 2021a).

This investigation aimed to examine the effect of various osmotic solution concentrations, temperatures, and immersion time on the mass transfer rate (rate of water loss – RWL, rate of solid gain – RSG, and rate of weight reduction – RWR) and the efficiency of osmotic treatment of domestic peach samples in sugar beet molasses (weight reduction – WR – and dehydration efficiency index – DEI).

2. Materials and methods

Fruit material and osmotic solution

Fresh peaches (*Prunus persica*, var. *nucipersica*) were bought at the local market, with the initial dry matter content of fruit pulp: 7.40 ± 0.08%, were prepared by washing with running water, drying with paper towels, and peeling and cutting into cubes of about 1 × 1 × 1 cm.

Sugar beet molasses, obtained from the sugar factory Crvenka, Serbia, with a dry matter content of 85.04%, was used to prepare osmotic solutions. Sugar beet molasses was diluted to the concentrations of 60%, 70%, and 80% of dry matter by distilled water to prepare osmotic solutions.

Osmotic treatment

The osmotic dehydration treatment was conducted in laboratory jars, under atmospheric pressure, at a constant temperature of 20, 35, or 50°C, in a thermostat chamber (Memmert IN160, Germany) for 1, 3, and 5 hours respectively. Nine laboratory jars were used (three for each temperature); in each of them, 50 g of peaches were immersed in sugar beet molasses solution using a mash lid. The peach samples to molasses solution weight ratio were 1:5. After immersion in molasses, peach samples were stirred manually every 15 minutes to enhance the diffusion of the leaked water from the peach surface into the molasses. After the treatment time (1 h, 3 hrs, and 5 hrs), samples were taken out from the molasses solutions, quickly washed with water stream, and gently blotted to remove the excess of water. The dry matter content of osmotically dehydrated samples was determined by drying at 105°C for 24 hrs in a heat chamber (Instrumentaria Sutjeska, Croatia) until reaching constant weight. All analytical measurements were carried out following AOAC (2000).

Calculations

Calculations of osmotic parameters (rate of water loss – RWL, rate of solid gain – RSG, weight reduction – WR, rate of weight reduction – RWR) during the osmotic treatment of peach were performed as described by *Koprivica et al.* (2010).

Statistical analysis

The principal component analysis (PCA) has been applied effectively to classify and segregate the different samples. The analysis of variance (ANOVA) and PCA were performed using StatSoft Statistical software v.10 (Stat soft Inc., Tulsa, OK, USA). R Studio 1.4.1106 program was used for colour correlation graph between the obtained mass transfer rate parameters, the WR and DEI of peach samples.

3. Results and discussions

Table 1 displays the average values and standard deviations of the mass transfer rate, weight reduction, and dehydration index during the osmotic treatment of peach samples as a function of immersion time, osmotic solution concentration, and temperature. Based on the obtained results, osmotic treatment was the most intensive initially. Also, it can be noticed that higher values of mass transfer rate were obtained at higher concentrations of sugar beet molasses solution and a higher temperature.

ANOVA showed that for RWL, RSG, RWR, WR, and DEI values, there was a significant statistical difference between the values of the peach samples osmotically treated for 1, 3, and 5 hours. In addition, there is a significant statistical difference between the values of the peach samples osmotically treated at different molasses solution concentrations (60%, 70%, and 80% w/w) and temperatures (20, 35, and 50°C).

Table 1. Mass transfer rate, weight reduction, and dehydration index during the osmotic treatment of peaches

No.	t (h)	C (% w/w)	T (°C)	RWL $g/(g_{i.s.w.}\cdot s)\cdot 10^5$	RSG $g/(g_{i.s.w.}\cdot s)\cdot 10^5$	RWR $g/(g_{i.s.w.}\cdot s)\cdot 10^5$	WR $g/g_{i.s.w}$	DEI
1	1	60	20	8.79 ± 0.04^{l}	0.53 ± 0.01^{f}	8.25 ± 0.10^{k}	0.30 ± 0.002^{a}	8.84 ± 0.17^{p}
2	3	60	20	4.50 ± 0.04^{f}	0.43 ± 0.07^{c}	4.12 ± 0.03^{e}	0.44 ± 0.003^{f}	5.48 ± 0.11^{hi}
3	5	60	20	3.29 ± 0.02^{a}	0.32 ± 0.02^{a}	2.97 ± 0.03^{a}	0.54 ± 0.001^{k}	5.41 ± 0.04^{gh}
4	1	70	20	9.78 ± 0.01^{m}	0.84 ± 0.01^{l}	8.71 ± 0.01^{l}	0.31 ± 0.002^{b}	6.45 ± 0.04^{lm}
5	3	70	20	4.81 ± 0.09^{g}	0.39 ± 0.01^{b}	4.41 ± 0.09^{f}	0.47 ± 0.004^{g}	6.49 ± 0.09^{n}
6	5	70	20	3.40 ± 0.06^{ab}	0.32 ± 0.02^{a}	3.08 ± 0.03^{a}	0.55 ± 0.002^{lm}	5.56 ± 0.05^{ij}
7	1	80	20	11.67 ± 0.06^{p}	1.06 ± 0.01^{n}	10.61 ± 0.05^{o}	0.38 ± 0.001^{d}	5.94 ± 0.06^{jk}
8	3	80	20	5.18 ± 0.03^{h}	0.47 ± 0.01^{l}	4.72 ± 0.12^{g}	0.51 ± 0.004^{hi}	5.13 ± 0.05^{kl}
9	5	80	20	3.81 ± 0.04^{cd}	0.39 ± 0.04^{b}	3.44 ± 0.01^{cd}	0.61 ± 0.005^{op}	4.82 ± 0.05^{f}
10	1	60	35	9.92 ± 0.01^{m}	0.84 ± 0.02^{l}	8.95 ± 0.01^{l}	0.32 ± 0.001^{b}	5.51 ± 0.12^{m}
11	3	60	35	4.98 ± 0.10^{gh}	0.38 ± 0.01^{b}	4.60 ± 0.04^{fg}	0.49 ± 0.005^{h}	6.08 ± 0.22^{o}
12	5	60	35	3.44 ± 0.05^{ab}	0.32 ± 0.03^{a}	3.11 ± 0.03^{ab}	0.56 ± 0.005^{mn}	5.77 ± 0.10^{ij}
13	1	70	35	10.43 ± 0.04^{n}	0.94 ± 0.01^{m}	9.43 ± 0.01^{m}	0.34 ± 0.001^{c}	5.19 ± 0.12^{kl}
14	3	70	35	5.57 ± 0.08^{i}	0.48 ± 0.02^{e}	5.00 ± 0.07^{h}	0.54 ± 0.001^{kl}	5.52 ± 0.10^{k}
15	5	70	35	3.86 ± 0.07^{d}	0.35 ± 0.04^{l}	3.56 ± 0.02^{cd}	0.64 ± 0.002^{q}	5.31 ± 0.11^{lm}
16	1	80	35	11.05 ± 0.07^{o}	1.03 ± 0.02^{n}	10.12 ± 0.03^{n}	0.36 ± 0.003^{d}	4.83 ± 0.07^{ij}
17	3	80	35	5.70 ± 0.05^{i}	0.50 ± 0.04^{e}	5.23 ± 0.02^{hi}	0.56 ± 0.007^{lm}	5.57 ± 0.04^{lm}
18	5	80	35	3.95 ± 0.05^{de}	0.39 ± 0.01^{b}	3.64 ± 0.03^{d}	0.64 ± 0.001^{q}	5.29 ± 0.19^{g}
19	1	60	50	11.34 ± 0.02^{op}	1.18 ± 0.02^{l}	10.05 ± 0.01^{n}	0.36 ± 0.004^{d}	5.55 ± 0.060^{f}

No.	t (h)	C (% w/w)	T (°C)	RWL $g/(g_{i.s.w.}\cdot s)\cdot 10^5$	RSG $g/(g_{i.s.w.}\cdot s)\cdot 10^5$	RWR $g/(g_{i.s.w.}\cdot s)\cdot 10^5$	WR $g/g_{i.s.w}$	DEI
20	3	60	50	5.43 ± 0.06^{i}	0.67 ± 0.01^{l}	4.84 ± 0.06^{g}	0.52 ± 0.002^{ij}	4.31 ± 0.06^{d}
21	5	60	50	3.59 ± 0.05^{bc}	0.53 ± 0.04^{l}	3.10 ± 0.08^{a}	0.56 ± 0.005^{lm}	3.92 ± 0.06^{a}
22	1	70	50	13.08 ± 0.01^{q}	1.49 ± 0.02^{l}	11.40 ± 0.01^{p}	0.42 ± 0.001^{e}	4.73 ± 0.08^{e}
23	3	70	50	6.23 ± 0.16^{j}	0.79 ± 0.01^{l}	5.37 ± 0.05^{i}	0.58 ± 0.005^{n}	4.78 ± 0.07^{c}
24	5	70	50	3.87 ± 0.05^{d}	0.55 ± 0.01^{l}	3.38 ± 0.03^{bc}	0.61 ± 0.007^{o}	3.95 ± 0.03^{ab}
25	1	80	50	13.33 ± 0.02^{r}	1.85 ± 0.04^{l}	11.51 ± 0.02^{p}	0.41 ± 0.004^{e}	3.20 ± 0.05^{b}
26	3	80	50	6.52 ± 0.03^{k}	0.72 ± 0.02^{l}	5.69 ± 0.17^{j}	0.62 ± 0.003^{p}	5.01 ± 0.07^{e}
27	5	80	50	4.23 ± 0.05^{e}	0.60 ± 0.01^{l}	3.63 ± 0.03^{cd}	0.65 ± 0.006^{q}	3.03 ± 0.01^{ab}

Note: $^{a-r}$ – the different letters in the superscript of the datasets regarding peach samples indicate a statistically significant difference between values, at a level of significance of $p < 0.05$.

Water loss rates, solid gain rates, and mass reduction rates showed the highest values during the first hour of the osmotic treatment. As previously noticed in other research (*González-Pérez et al.*, 2021; *Prithani & Dash*, 2020; *Assis et al.*, 2016; *Nićetin et al.*, 2014), the mass transfer rate decreased continuously from the first to the third hour, and after the third hour it showed a tendency of slowing down. The mass transfer rate was intensive when peach samples were osmotically treated in the most concentrated solution and at the highest temperature because of a more significant difference between the osmotic pressures of the hypertonic medium and the peach samples' tissue. The highest values for RWL, RSG, and RWR (13.33 ± 0.02, 1.85 ± 0.04, and 11.51 ± 0.02 respectively) were obtained after 1 h of osmotic treatment in a sugar beet molasses solution of 80% w/w concentration and with a temperature of 50 °C.

Weight reduction (WR) occurred due to water transfer from the peach sample in the osmotic medium and the smaller extent diluted nutrients from the sugar beet molasses solution into the immersed peach pieces. Osmotic treatment results in the reduced mass of the samples as a consequence; the food samples lose weight and shrink (*Chandra & Kumari*, 2015). From *Table 1*, it can be seen that the highest value of WR was reached after 5 hrs; using 80% sugar beet molasses solution at 50°C, the WR value was 0.65 g/g of the initial sample weight. The sample mass was reduced the most rapidly in the first three hours of the process.

The value of DEI is the most crucial criterion of the efficiency of the osmotic treatment (*Ćurčić et al.*, 2014). Considering the fact that DEI represents a ratio of water loss and solid gain during the treatment, a higher concentration of the osmotic medium tends towards the diffusion of solids into the sample, which results in a reduction in the value of DEI. The highest value of DEI was noticed at the beginning of the process: 8.84 ± 0.17. The tendency of DEI decrease could be explained by solid gain increase of peach from the molasses during the osmotic treatment process. This phenomenon had a positive effect on the chemical composition of dehydrated samples, considering the rich nutritional composition of sugar beet molasses (*Lončar et al.*, 2021; *Nićetin et al.*, 2021).

The obtained correlations were illustrated in *Figure 1*, employing the "corrplot" function from the R Studio 1.4.1106 program. The colour is based on the correlation coefficients and indicates a relation between two samples; if the colour is blue, the positive correlation was accomplished; on the contrary, the red colour symbolizes negative correlation between the samples. The darker blue tone of the squares suggests a stronger correlation between these samples, while the lighter tone indicates an evident dissimilarity between the samples.

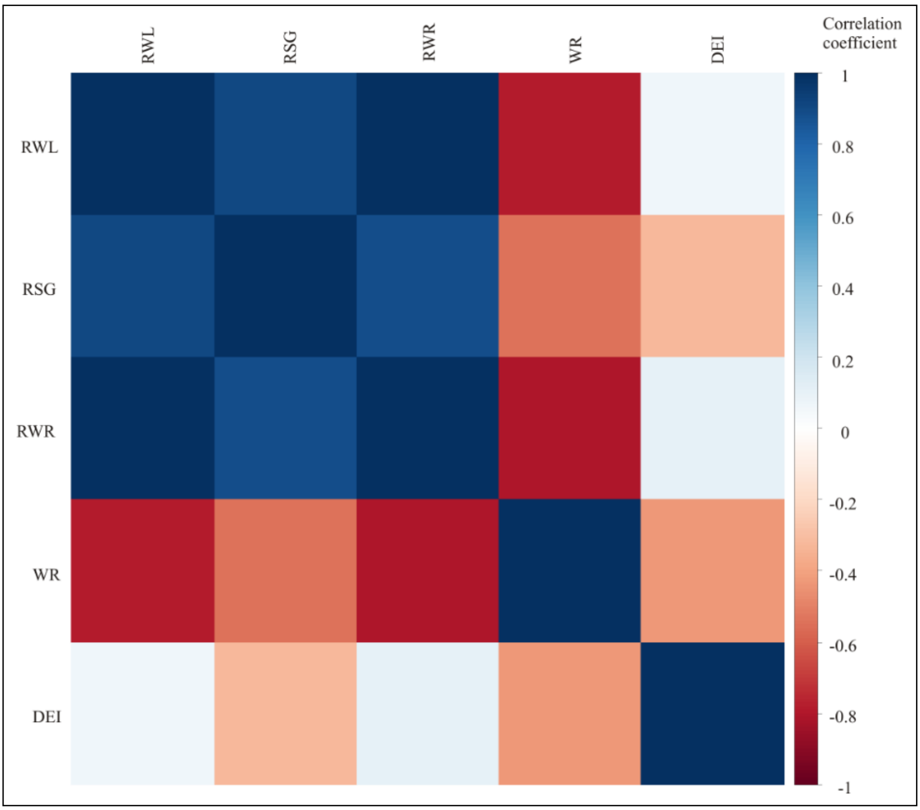

Figure 1. Colour correlation graph between obtained mass transfer rate parameters, WR and DEI of peach samples

From *Figure 1*, we can observe a positive correlation between RWL, RSG, and RWR and a negative correlation of these responses to WR.

In order to better explain the structure of the exploratory data that would contribute to the comprehension of likenesses and dissimilarities of the peach samples, PCA was applied, and the results are presented in *Figure 2*. The PCA of the mass transfer rate parameters, WR and DEI of the peach samples explained that the first two principal components summarized 81.93% of the total variance in the observed parameters. The projection of the factors indicated that RWL, RSG, RWR, and WR contributed mostly to the first principal component PC1 (28.25%, 22.58%, 28.28%, and 20.60% respectively), while the DEI contributed more to the second principal component PC2 (71.93%).

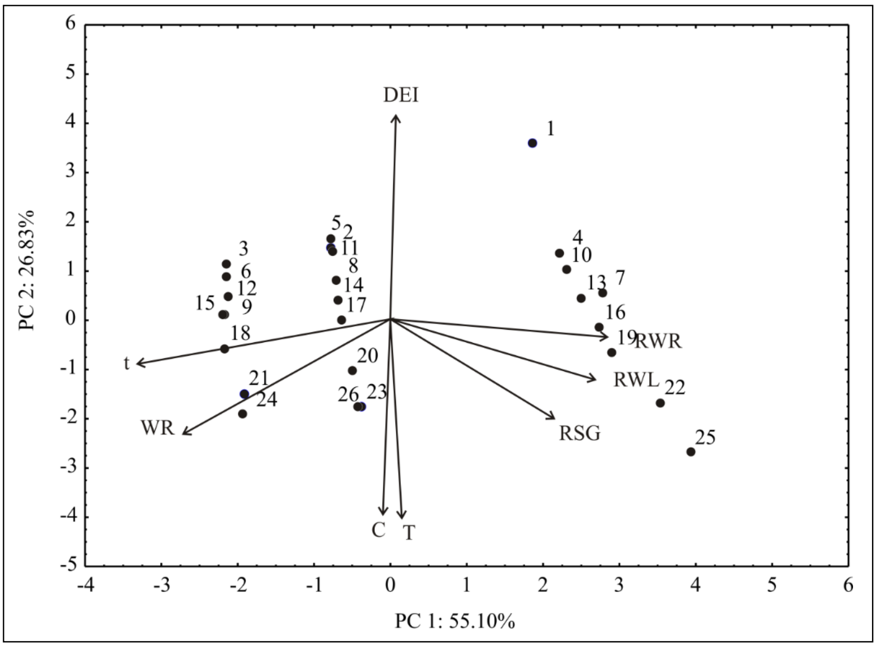

Figure 2. The PCA biplot diagram describing the relations between mass transfer rate parameters, WR and DEI of peach samples (the samples' codes are noted in *Table 1*)

4. Conclusions

Based on the given results, it can be concluded that sugar beet molasses is an effective osmotic solution for the osmotic treatment of peach samples. During the osmotic treatment of peach samples, the water-removing process was the most intensive at the beginning in all osmotic solutions. After 3 hours, it tended to slow down; therefore, 3 hours could be set as the processing time for the osmotic treatment of the peach. Osmotic dehydration provides a semi-product, and the desired final product is obtained in the second drying step using other dying methods. The PCA of the mass transfer rate parameters, weight reduction, and dehydration efficiency index of peach samples explained that the first two principal components summarized 81.93% of the total variance in the observed parameters.

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