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OSMOTIC TREATMENT OF ORANGE AND PINK SWEET POTATO-MASS TRANSFER RATE AND EFFICIENCY

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ABSTRACT

Sweet potatoes (*Ipomoea batatas*) are globally cultivated due to its adaptability, high nutritional value, and short growing season, tolerance to high-temperature soils, low fertility, and minimal pest or disease issues, making it a valuable asset to the food industry. Osmotic treatment, a renowned preservation technique requiring mild temperatures and minimal energy, has gained prominence. Over ten years of research at the Faculty of Technology Novi Sad has pioneered the use of sugar beet molasses as an effective osmotic solution for drying different herbs, fruits, vegetables, and meat. This study specifically focused on osmotically treating samples of pink and orange sweet potatoes in sugar beet molasses (80% w/w) to explore the influence of solution temperatures (20°C, 35°C, and 50°C) and osmotic treatment durations (1h, 3h, and 5h) on mass transfer rate and treatment efficiency. The Principal Component Analysis (PCA) and color correlation analysis were employed to illustrate the connections between different sweet potato samples. Findings indicate that the mass transfer rate peaks at the onset of the process. Particularly with the highest temperature after 1h of osmotic treatment The highest values for RWL and RSG (13.33±0.02, 1.85±0.04 and 11.51±0.02, accordingly) were obtained for both orange ((15.19±0.08 g/(gi.s.w.·s)·$10^5$and 4.53±0.06 g/(gi.s.w.·s)·10^5) and pink sweet potato ((9.91±0.02 g/(gi.s.w.·s)·10^5 and 3.78±0.04 g/(gi.s.w.·s)·10^5), respectively. Notably, diffusion is most rapid within the initial three hours, suggesting potential reductions in processing time aligned with these results.

Keywords: osmotic drying, sweet potato, sugar beet molasses, weight reduction, dehydration efficiency index, PCA, correlations

1. INTRODUCTION

Sweet potatoes (Ipomoea batatas) are cultivated worldwide and present important food source in tropical and subtropical regions. Notably, sweet potatoes boast higher levels of carbohydrates and dietary fiber compared to potatoes. The flesh color varies depending on the presence of pigments like carotenoids or anthocyanins, and their antioxidant activity is notable [1, 2]

To preserve sweet potatoes, various drying methods have been applied, including air drying [3], tin layer solar drying [4], hot air drying [5], microwave drying [6], microvave vacuum drying [7] and freeze-drying [8].

Osmotic treatment is efficient in removing water from food materials by immersing them in hypertonic solutions of high viscosity [9]. The difference between the osmotic pressure of immersed material and the osmotic medium is the driving force of the efficient osmotic treatment; therefore, selecting an adequate osmotic solution is essential [10].

Traditionally, sucrose and glucose solutions are usually used as an osmotic medium [11]. However, recent research offers a more creative approach using concentrated fruit juices [12] or unconventional sweeteners [13].

In this paper, sugar beet molasses has been selected as an osmotic medium due to available literature confirming its positive effects on different food materials, such as apples [14], cabbage [15], carrots [16], mushroom [17], peaches [18], wild garlic [19], celery [20], etc.

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This research aims to explore the osmotic treatment of pink and orange sweet potatoes in sugar beet molasses conducted at different solution temperatures and processing times, focusing on 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 (weight reduction – WR – and dehydration efficiency index – DEI).

2. MATERIALS AND METHODS

2.1. Materials

The sweet potatoes were purchased in local market in Novi Sad, Serbia. For this study, two different sweet potato varieties were used, with the difference in flesh color—orange and pink. Edible parts were separated (peeled) and sliced into 0.5 cm thickness and 3.6 cm diameter using a Nemco slicer (accuracy of ±0.27 mm) (55200AN, Hicksville, OH, USA). Sugar beet molasses was purchased from Farm Commerc doo., Čantavir, Serbia.

2.2. Osmotic dehydration

The osmotic treatment was performed in an 80% solution of sugar beet molasses, in laboratory jars, at three temperatures, 20°C, 35°C and 50°C for 1, 3 and 5 h, with samples to solution ratio of 1:5. The sweet potato samples were stirred manually every 15 minutes. After targeted time of osmotic treatment, samples were taken out from the sugar beet molasses solution lightly washed using distilled water, and gently blotted with tissue paper. The dry matter content of osmotically dehydrated samples was assessed by drying at 105°C for 24 hours in a heat chamber (Instrumentaria Sutjeska, Croatia) until a constant weight was achieved. All analytical measurements adhered to AOAC (2000) standards.

2.3. Calculations

The calculations of osmotic parameters, including the rate of water loss (RWL), rate of solid gain (RSG), weight reduction (WR), rate of weight reduction (RWR),dehydration efficiency index (DEI) during the osmotic treatment of sweet potato were conducted according to the following equations [21]:

$$WR = \frac{w_o - w}{w_o} \tag{1}$$

$$SG = \frac{u - u_o}{w_o} \tag{2}$$

$$WL = WR + SG \tag{3}$$

where: W_o- initial weight of the sweet potato sample (g), W – weight of the sweet potato sample after osmotic treatment (g), u_o – weight of dry matter in the fresh sweet potato sample (g), u- weight of dry matter in the sweet potato sample after osmotic dehydration (g).

Based on these parameters, dehydration efficiency index (DEI), the rate of solid gain (RSG), the rate of water loss (RWL) and the rate of weight reduction (RWR) were calculated during osmotic dehydration can be calculated:

$$DEI = \frac{Wl}{SG} \tag{4}$$

$$RSG = \frac{SG}{t} \tag{5}$$

$$RWL = \frac{WL}{t} \tag{6}$$

$$RWR = \frac{WR}{t} \tag{7}$$

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where t is processing time during osmotic treatment

2.4.Statistical analysis

The results were statistically evaluated using analysis of variance (ANOVA), principal component analysis (PCA) by StatSoft Statistical software v.10 (StatSoft Inc., Tulsa, OK, USA). The correlations between samples were visually illustrated using color correlation analysis performed in R Studio 1.4.1106 program.

3. RESULTS AND DISCUSSION

Tab. 1 and Tab. 2 provide detailed results from the osmotic dehydration in sugar beet molasses solution of orange and pink sweet potatoes, respectively, presenting the mean values and standard deviations for the mass transfer rate, weight reduction, and dehydration index observed during the treatment at three different temperatures and times. The results indicate that temperature and treatment duration significantly influence the mass transfer rates and efficiency of orange sweet potato osmotic treatment, Tab. 1. Higher temperatures generally lead to faster mass transfer during the treatment.

According to ANOVA analysis there is a statistically significant difference in RWL, RSG, RWR, WR, and DEI values among sweet potato samples subjected to osmotic treatment for 1, 3, and 5 hours. Furthermore, there was a significant statistical difference in values among sweet potato samples treated at different treatment temperatures (20, 35, and 50°C).

Table 1. The mass transfer rate and efficiency during the osmotic treatment of orange sweet potato

No.	Sample	t (h)	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 $g/(g_{i.s.w.}\cdot s)\cdot 105$	DEI	WR $g/g_{i.s.w}$
1	Orange	1	20	9.76 ± 0.02^d	4.01 ± 0.03^h	5.74 ± 0.02^e	7.75 ± 0.02^e	0.21 ± 0.00^a
2	Orange	3	20	7.38 ± 3.04^c	1.23 ± 0.01^g	4.39 ± 0.03^c	4.55 ± 0.01^c	0.52 ± 0.09^{dc}
3	Orange	5	20	3.91 ± 0.05^b	0.50 ± 0.01^c	3.39 ± 0.01^b	2.42 ± 0.01^a	0.61 ± 0.00^e
4	Orange	1	35	13.36 ± 0.15^e	0.93 ± 0.01^f	12.61 ± 0.07^g	9.91 ± 0.09^g	0.45 ± 0.00^{bc}
5	Orange	3	35	5.97 ± 0.02^{bc}	0.67 ± 0.01^d	5.07 ± 0.03^d	6.35 ± 0.01^d	0.54 ± 0.01^{ed}
6	Orange	5	35	0.39 ± 0.00^a	0.16 ± 0.00^b	0.23 ± 0.00^a	2.43 ± 0.00^a	0.41 ± 0.00^b
7	Orange	1	50	15.19 ± 0.08^e	4.53 ± 0.06^i	10.47 ± 0.05^f	8.37 ± 0.02^f	0.38 ± 0.00^b
8	Orange	3	50	6.46 ± 0.09^{bc}	0.77 ± 0.00^e	5.65 ± 0.05^e	4.46 ± 0.01^c	0.60 ± 0.01^e
9	Orange	5	50	0.43 ± 0.00^a	0.10 ± 0.00^a	0.33 ± 0.00^a	3.29 ± 0.00^b	0.61 ± 0.00^e

$^{a–i}$ Means in the same column with different superscripts are statistically different ($p \leq 0.05$).

Table 2. The mass transfer rate and efficiency during the osmotic treatment of pink sweet potato

No.	Sample	t (h)	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 $g/(g_{i.s.w.}\cdot s)\cdot 10^5$	DEI	WR g/gi.s.w

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1	pink	1	20	6.67±0.04[c]	1.50±0.01[f]	5.70±0.04[h]	5.83±0.03[c]	0.22±0.00[a]
2	pink	3	20	4.64±1.07[b]	0.92±0.00[d]	4.35±0.03[g]	5.75±2.38[c]	0.47±0.00[d]
3	pink	5	20	3.64±0.02[b]	0.63±0.00[b]	3.00±0.00[c]	2.63±0.04[a]	0.54±0.00[e]
4	pink	1	35	6.00±0.03c	1.89±0.01[g]	4.09±0.04[f]	5.54±0.01[bc]	0.45±0.00[c]
5	pink	3	35	4.06±0.02[b]	0.89±0.00[c]	3.18±0.01[d]	4.55±0.04[abc]	0.44±0.00[c]
6	pink	5	35	1.51±0.00[a]	0.27±0.00[a]	1.24±0.01[a]	3.17±0.03[a]	0.57±0.01[f]
7	pink	1	50	9.89±0.03[d]	3.80±0.01[h]	6.14±0.01[i]	6.45±0.07[c]	0.38±0.00[b]
8	pink	3	50	4.29±0.03[b]	1.05±0.01[e]	3.40±0.02[e]	4.71±0.03[abc]	0.60±0.00[g]
9	pink	5	50	1.50±0.01[a]	0.91±0.00[cd]	1.50±0.02[b]	3.32±0.02[ab]	0.62±0.01g

[a–i] Means in the same column with different superscripts are statistically different ($p \leq 0.05$).

For both orange and pink sweet potato samples it was noticed that the rates of water loss, solid gain, and mass reduction reached their peak values within the initial hour of the osmotic treatment. Tab. 1 shows that, after 1 hour of osmotic treatment of orange sweet potato samples at 50°C, the highest values for RWL, RSG, and RWR were attained, measuring 15.19±0.08, 4.53±0.06 and 10.47±0.05, respectively. The results for the pink sweet potato samples showed the same trend, however lower values were obtained for RWL (6.67±0.04) RSG (1.50±0.01), and RWR (5.70±0.04), Table 2. As observed in earlier studies [21-23], the mass transfer rate exhibited a continuous decrease from the initial to the third hour of the experiment, with a tendency to slow down thereafter.

The dehydration efficiency index stands out as the key criterion for assessing the efficiency of the osmotic treatment [24]. The DEI, representing the ratio of water loss to solid gain during osmotic treatment, tends to decrease during osmotic treatment, as it can be observed for Tab. 1 and Tab. 2. The highest DEI values were observed at the begging of the process for both sweet potato varieties.

Osmotic treatment reduced the weight of both sweet potatoes varieties samples by facilitating water transfer into the osmotic medium and diluting nutrients from the sugar beet molasses solution into the immersed samples, resulting in decreased sample mass and shrinkage [25]. From Tab.1 and Tab. 2, it can be seen that the highest value of weight reduction was obtained after 5 h at the highest temperature, the WR values for orange and pink sweet potato samples were 0.61g/g and 0.62g of the initial sample weight, respectively. For both sweet potatoes varieties samples the weight reduction was the most pronounced in the first three hours of the osmotic treatment. These findings underscore the importance of considering both temperature and duration in osmotic treatments for optimal results in terms of mass transfer efficiency.

3.1. Color correlation analysis

Fig. 1 illustrates a color correlation diagram depicting all observed responses of the tested orange sweet potatoes samples. The color (blue for positive and red for negative) and the circle size represent the correlation coefficients between the two observed responses [26]. There is a high positive correlation between RWL and RSG, also RWL and RWR ($r = 0.701$, and $r=0.939$, statistically significant at $p < 0.05$ respectively), on the other hand, a negative correlation is observed between RWL and WR ($r=-0.431$,

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statistically significant at $p < 0.05$ respectively). Furthermore, RSG is positively correlated with RWR (r = 0.487), while negatively correlated with WR (r=-0.733, statistically significant at $p < 0.05$). There is also a positive correlation between RWR and DEI (r=0.618, statistically significant at $p < 0.05$ respectively).

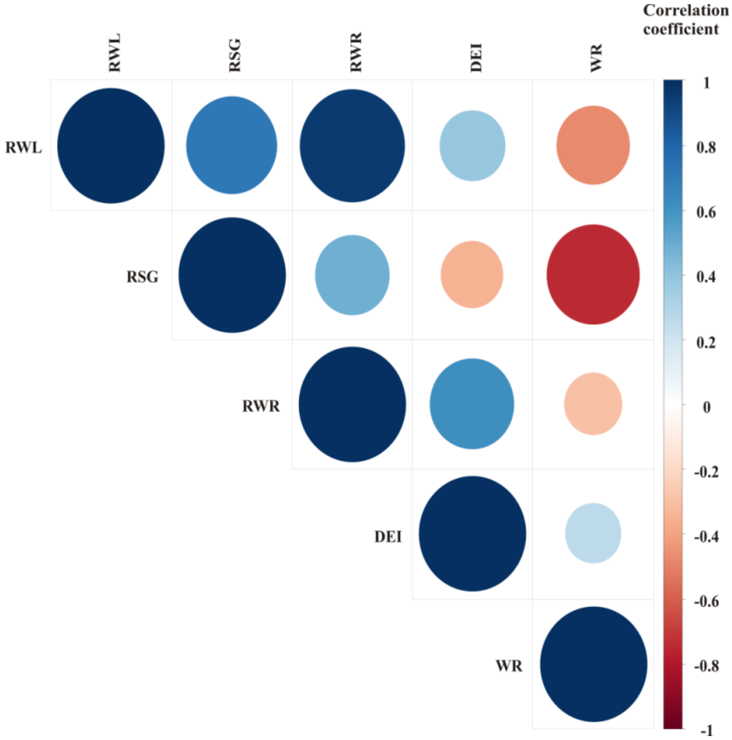

Figure 1*. The color correlation graph for osmotically treated orange sweet potatoes for all observed parameters*

Additionally, correlation analysis was conducted to explore the resemblances between observed parameters among various pink sweet potato samples. The findings are illustrated graphically in Fig. 2. Observing Fig. 2, it is evident that there is a high positive correlation between RWL and RSG, also RWL and RWR (r = 0.777, and r=0.944, statistically significant at $p < 0.05$ respectively). Furthermore, positive correlation is also observed between RSG and RWR (r = 0.609) and DEI and WR (r = 0.651, statistically significant at $p < 0.05$). On the other hand, RSG is negatively correlated with DEI and WR (r = -0.692, and r=-0.778, statistically significant at $p < 0.05$ respectively).

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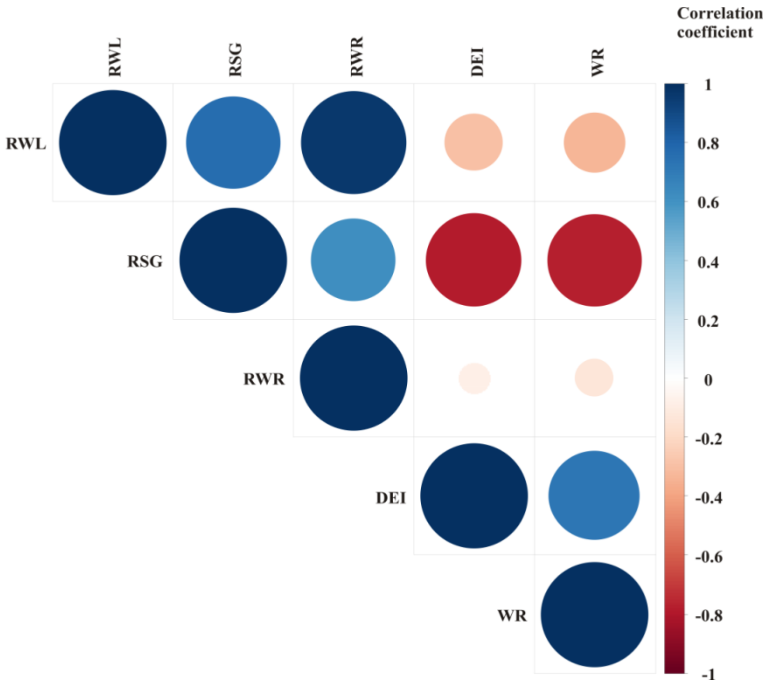

***Figure 2**. The color correlation graph for osmotically treated pink sweet potatoes for all observed parameters*

3.2. Principal Component analysis

PCA analysis was conducted as depicted in Fig. 3 and Fig. 4. The PCA biplot in Fig. 3 illustrates the relationships among observed parameters of mass transfer rate and osmotic treatment efficiency for the orange sweet potato samples. It was found that the first two principal components accounted for 80.57% of the total variance in the observed parameters. According to the results of the PCA, t, RWL, RSG, and RWR (which contributed 24.92%. 24.67%. 16.47%. and 20.79% of the total variance. based on correlations. respectively) showed a positive influence on PC1. Furthermore, T (8.40%), DEI (42.59%), and WR (22.11%) positively influenced the calculation of PC2, (Fig. 3).

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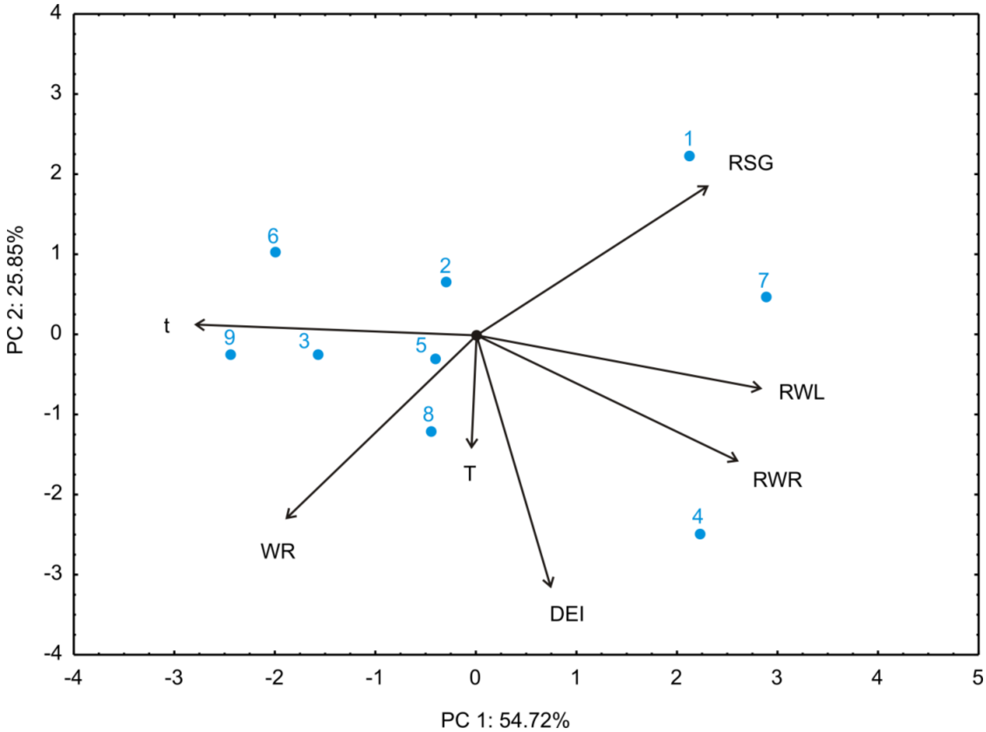

Figure 3. *The PCA biplot diagram illustrating the relationships among mass transfer rate parameters. WR. and DEI of orange sweet potato samples. with the corresponding sample codes given in Tab. 1.*

On the other hand, the PCA biplot in Fig.4 depicts the relationships among observed parameters of mass transfer rate and osmotic treatment efficiency for the pink sweet potato samples. It was found that the first two principal components accounted for 77.27% of the total variance in the observed parameters. Based on the PCA results, T, RSG, DEI, and WR, which contributed 4.63%, 26.38%, 14.46%, and 19.90% of the total variance respectively. demonstrated a positive impact on PC1. Additionally, t (23.65%), RWL (20.87%), and RWR (30.58%) positively influenced the calculation of PC2, as illustrated in Fig. 4.

There is a more pronounced separation between samples of orange sweet potato by processing time. It can be noticed from the Fig. 3, that samples threaded for 1 h are organized on the right side of the biplot, the samples dehydrated for 3 h are grouped on the left side, while the samples osmotically treated for 5h are in the center. On the other hand, the organization for the samples in Fig. 4 is not that obvious.

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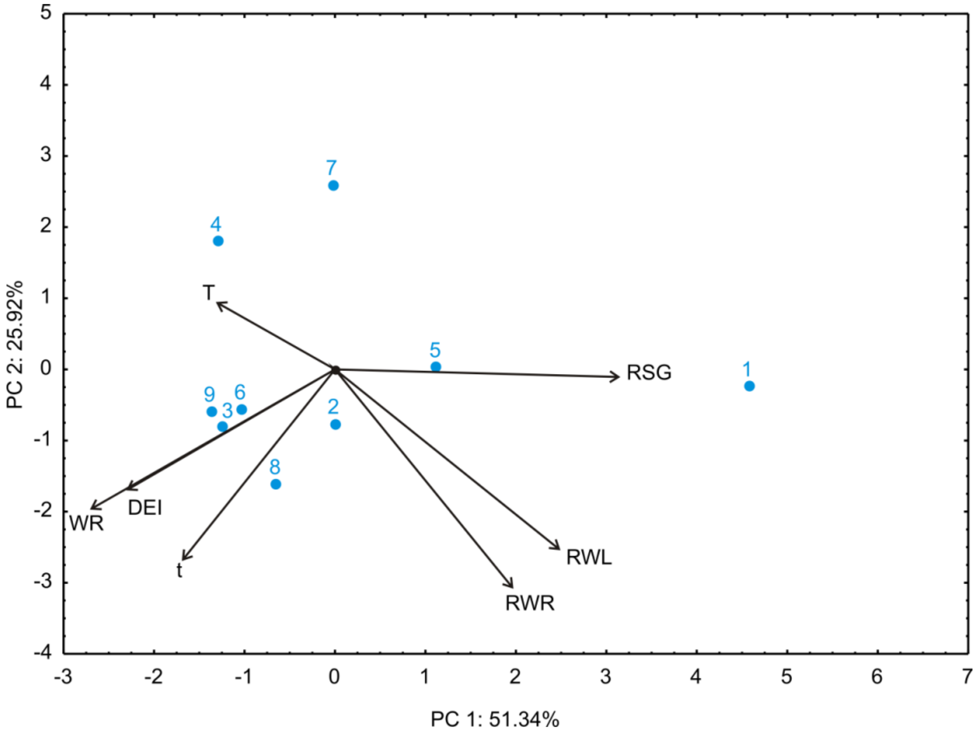

Figure 4 *The PCA biplot diagram illustrating the relationships among mass transfer rate parameters, WR, and DEI of pink sweet potato samples. with the corresponding sample codes given in Tab.2.*

4. CONCLUSIONS

In conclusion, the presented results provide insights into the osmotic treatment of orange and pink sweet potatoes in sugar beet molasses, revealing significant effects of temperature and treatment duration on mass transfer rates and efficiency. Both varieties exhibited peak values of water loss, solid gain, and mass reduction within the initial hour of treatment. The dehydration efficiency index tended to decrease during treatment, with the highest values observed initially. Osmotic treatment resulted in weight reduction through water transfer and nutrient dilution, with maximum reductions observed after 5 hours at the highest temperature. Correlation analysis revealed significant relationships among various parameters, emphasizing the importance of considering both temperature and duration for optimal osmotic treatment outcomes, while PCA analysis provided further insights into the treatment efficiency for both sweet potato varieties.

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